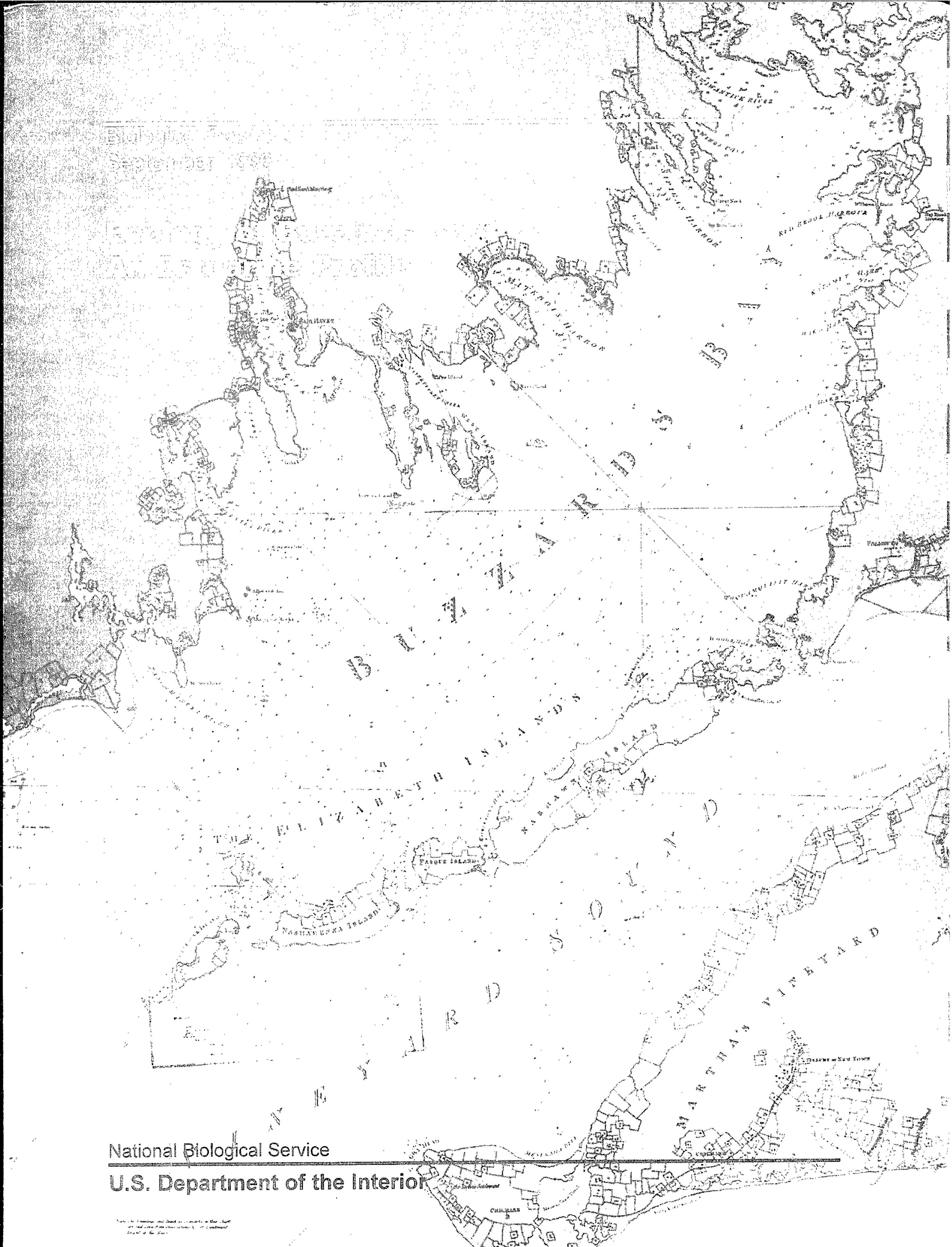
Biological Report

September 1996



National Biological Service

U.S. Department of the Interior

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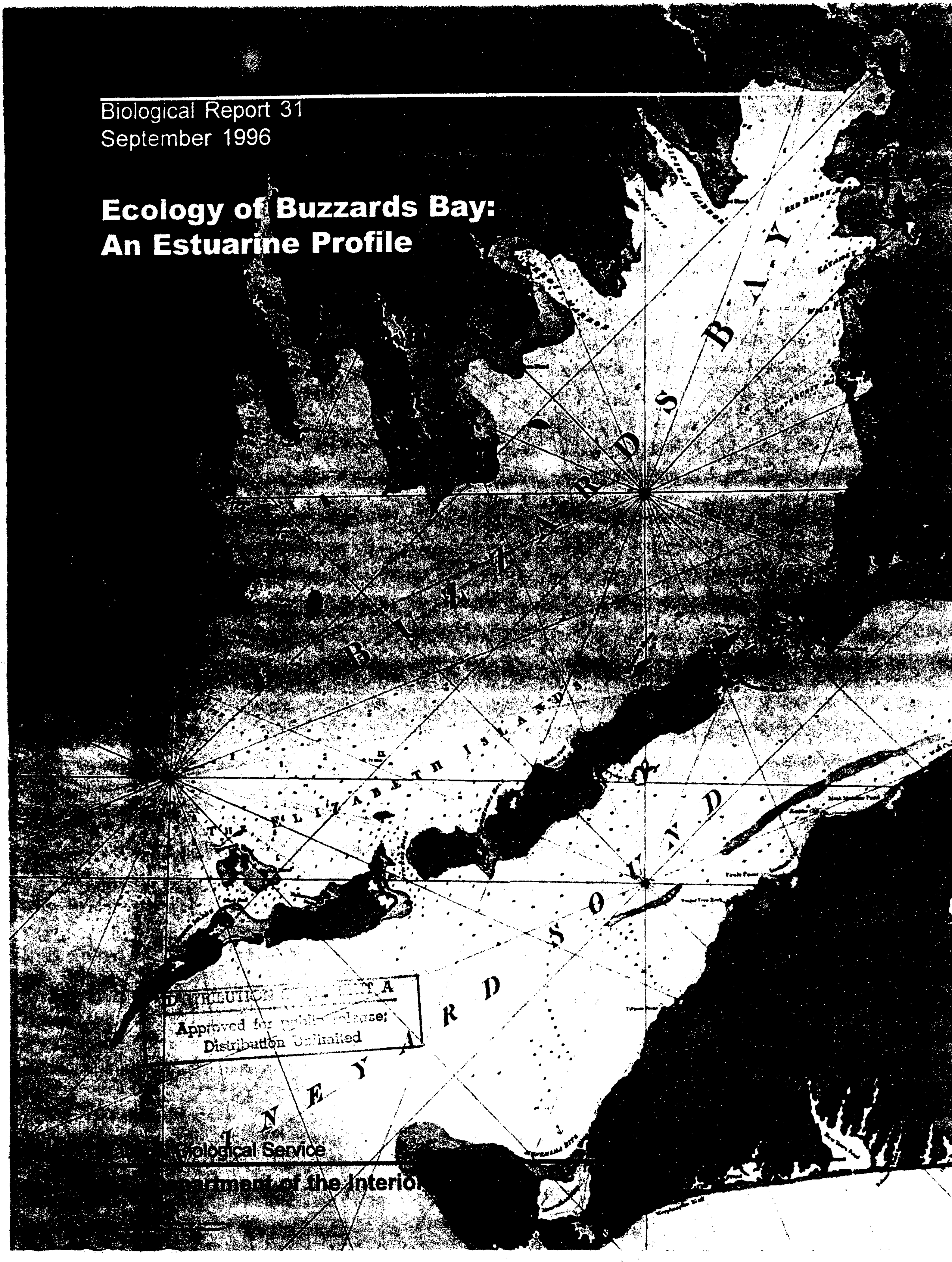
Ecology of Buzzards Bay: An Estuarine Profile



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Funding for printing this report was provided by the NBS National Wetlands Research Center, Lafayette, LA. Production was also by the NBS National Wetlands Research Center, Lafayette, LA (see inside back cover).

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REPORT DOCUMENTATION PAGE	Form approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE
September 1996

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Ecology of Buzzards Bay: An Estuarine Profile

5. FUNDING NUMBERS

6. AUTHOR(S)
B.L. Howes and D.D. Goehringer

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSES
Biological Department
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

Coastal Ecological Research Institute
at Woods Hole
Woods Hole, MA 02543

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESSES
U.S. Department of the Interior
National Biological Service
Washington, DC 20240

10. SPONSORING, MONITORING AGENCY REPORT NUMBER
Biological Report 31

11. SUPPLEMENTARY NOTES
Errata sheet added.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Release unlimited. NTIS, DoDD

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Buzzards Bay remains one of the few relatively pristine bays in the metropolitan corridor from Washington to Boston. The bay and its surrounding marshes and uplands have provided a variety of biotic resources not only to European settlers over nearly 400 years but also to the Native Americans who relied on this estuary for thousands of years before them. Today the uplands are divided between 18 communities, and while the bay is still exploited for its biotic resources, its aesthetic and recreational values add to the growing concern to preserve its environmental quality. At the same time, it has become clear that the health of the Buzzards Bay ecosystem, like almost all estuarine systems, is controlled not just by processes within the bay waters themselves but also by inputs from the surrounding uplands as well. Therefore, to properly understand and manage this system, it is important to detail activities and land use patterns within the watershed as well as within the tidal reach of the bay waters. This combined watershed-bay system is referred to as the "Buzzards Bay Ecosystem" and is the necessary frame of reference for understanding the biotic structure of the bay and for managing and conserving its resources.

This community profile provides an overview of the ecology of the Buzzards Bay ecosystem. It is not intended to represent an all-inclusive review of the literature; instead it is an attempt to present key features of the bay in a readily accessible form and to summarize the dominant ecological processes that structure the bay environment. Because the current and future environmental health of these types of embayments can be directly influenced by activities within contributing watersheds, understanding the interactions between land and sea is an important component to understanding the ecosystem as a whole. The subjects addressed in this profile, therefore, focus not only on the open bay waters but also on the ecology of Buzzards Bay within its watershed including management issues and the difficulties in balancing demands for access and development while protecting water quality.

14. SUBJECT TERMS (Keywords)
Buzzards Bay, estuarine ecology, ecosystem, watershed

15. NUMBER OF PAGES
vi + 141 pp.

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

U.S. DEPARTMENT OF THE INTERIOR
NATIONAL BIOLOGICAL SERVICE

Biological Report 31
September 1996

Ecology of Buzzards Bay: An Estuarine Profile

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Washington, D.C. 20240

Errata Sheet for: Howes, B.L., and D.D. Goehringer.1996. Ecology of Buzzards Bay: an estuarine profile.

The correct number for this report is Biological Report 33.

The front cover, title page, and spine copy should read Biological Report 33

The suggested citation on page *ii* should read:
Howes, B.L., and D.D. Goehringer.1996. Ecology of Buzzards Bay: an estuarine profile. National Biological Service Biological Report 33. vi+141 pp.

The headers on even-numbered pages should read Biological Report 33.

Block 10 of the Report Documentation Page (SF298) should read Biological Report 33.

004

Suggested citation:
Howes, B.L., and D.D. Goehringer. 1996. Ecology of Buzzards Bay: an estuarine profile. National Biological Service Biological Report 31. vi + 141 pp.

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Preface

Buzzards Bay, described by Gabriel Archer in an account of Bartholomew Gosnold's discovery in 1602 as "the stateliest sound I was ever in," remains one of the few relatively pristine bays in the metropolitan corridor from Washington to Boston. The bay and its surrounding marshes and uplands have provided a variety of biotic resources not only to European settlers over nearly 400 years but also to the Native Americans who relied on this estuary for thousands of years before them. Today the uplands are divided between 18 communities and although the bay is still exploited for its biotic resources, its aesthetic and recreational values add to the growing concern to preserve its environmental quality. At the same time, the health of the Buzzards Bay ecosystem, like that of almost all estuarine systems, is clearly controlled not just by processes within the bay waters themselves but also by inputs from the surrounding uplands as well. Therefore, to properly understand and manage this system, it is important to describe in detail activities and land use patterns within the watershed as well as within the tidal reach of the bay waters. This combined watershed-bay system is referred to as the "Buzzards Bay Ecosystem" and is the necessary frame of reference for understanding the biotic structure of the bay and for managing and conserving its resources.

Located in southeastern Massachusetts, Buzzards Bay and its watershed have long been of interest to biologists because of their geographical positioning between several major water masses along the North Atlantic coast of the United States. This led to the establishment of several major marine research centers, the U.S. Fish Commission in 1871 (now the National Marine Fisheries Service), the Marine Biological Laboratory in 1888, and the Woods Hole Oceanographic Institution in 1930.

Buzzards Bay's undulating shoreline contains numerous natural harbors and coves, which support diverse floral and faunal communities as well as commercial and recreational resources. The port of New Bedford, located on the southwestern shore, is the major industrial and business center within the Buzzards Bay watershed. Well known historically as a hub of the whaling industry in the early 1800's, New Bedford remains an active fishing port (coastal and offshore) for the region and represents the largest revenue-producing fishing port on the east coast of the United States (Weaver 1984). The problems facing Buzzards Bay fisheries more than 100 years ago (e.g., overfishing and restriction of inland waterways; Baird 1873) still exist; however, the problem of coastal pollution has been revived as a potential factor in the apparent decline of the area's fisheries. In addition to the historic pollutants (urban runoff, heavy metals), the discovery of polychlorinated biphenyl (PCB) pollution in the waters and sediments of New Bedford Harbor in 1976 (Farrington et al. 1984; Weaver 1984) and the rapid human population growth within the Buzzards Bay watershed have refocused attention and resulted in a renewed scientific interest in the bay and its environs.

In 1984, Buzzards Bay became one of four estuaries then making up the National Estuary Program. In 1985, through a joint effort of the U.S. Environmental Protection Agency and the Massachusetts Executive Office of Environmental Affairs, the Buzzards Bay Project was established to develop strategies for protecting the bay's natural resources. The Comprehensive Conservation and Management Plan for Buzzards Bay, released in 1991, focused on three priority problems: closure of shellfish beds, contamination of fish and shellfish by toxic metals and organic compounds, and potential water quality degradation resulting from excessive nutrient loading. Both the Buzzards Bay Project and the Comprehensive Conservation and Management Plan are aimed at developing recommendations for regional water quality management based on sound information, defining the regulatory and management structure necessary to implement the

recommendations, and educating and involving the public in the formulation and implementation of these recommendations.

The purpose of this report is to provide an overview of the ecology of the Buzzards Bay ecosystem. It is not intended to represent an inclusive review of the literature, but instead is an attempt to present key features of the bay in a readily accessible form and to summarize the dominant ecological processes structuring the bay environment. Because the current and future environmental health of these types of embayments can be directly influenced by activities within contributing watersheds, understanding the interactions between land and sea is important to understanding the ecosystem as a whole. The subjects addressed in this profile, therefore, focus not only on the open bay waters but also on the ecology of Buzzards Bay within its watershed. After a general introduction to the system, the formation of the bay is discussed in Chapter 2, followed by descriptions of the physical (Chapter 3) and biological (Chapter 4) components of the system and their interaction. Chapter 5 addresses watershed land use and water quality issues within the bay proper and its circulation-restricted coastal embayments, while natural and anthropogenic influences responsible for present and future changes to bay systems are the focus of Chapter 6. We conclude with a summary of management issues and the difficulties in balancing demands for access and development while protecting water quality (Chapter 7).

Although Buzzards Bay is an important environmental and economic resource for New England, ecosystem level information is still rather limited in some areas. We hope that this monograph will not only act as a reference for researchers, managers, and citizens interested in the bay but may also serve to point out major gaps in our knowledge of this system. Two previous community profiles (Nixon 1982; Teal 1986) may be particularly useful companion texts providing more detailed information on saltwater wetlands in southeastern Massachusetts, including Buzzards Bay.

While Bartholomew Gosnold would certainly be taken aback by the alterations wrought within his stately sound's watershed, areas of the bay itself remain much as when he sailed them almost 400 years ago. However, many activities and the increasing pressures of development are beginning to significantly alter this system, and only management from a whole system perspective will be effective in protecting this resource that attracts so many.

This estuarine profile was originally intended to be one in a series originally coordinated by the U.S. Fish and Wildlife Service's National Wetlands Research Center, now part of the National Biological Service. Questions or comments concerning this publication or others in the community and estuarine profile series should be directed to:

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Abstract. Buzzards Bay remains one of the few relatively pristine bays in the metropolitan corridor from Washington to Boston. The bay and its surrounding marshes and uplands have provided a variety of biotic resources not only to European settlers over nearly 400 years but also to the Native Americans who relied on this estuary for thousands of years before them. Today the uplands are divided between 18 communities, and while the bay is still exploited for its biotic resources, its aesthetic and recreational values add to the growing concern to preserve its environmental quality. At the same time, it has become clear that the health of the Buzzards Bay ecosystem, like almost all estuarine systems, is controlled not just by processes within the bay waters themselves but also by inputs from the surrounding uplands as well. Therefore, to properly understand and manage this system, it is important to detail activities and land use patterns within the watershed as well as within the tidal reach of the bay waters. This combined watershed-bay system is referred to as the "Buzzards Bay Ecosystem" and is the necessary frame of reference for understanding the biotic structure of the bay and for managing and conserving its resources.

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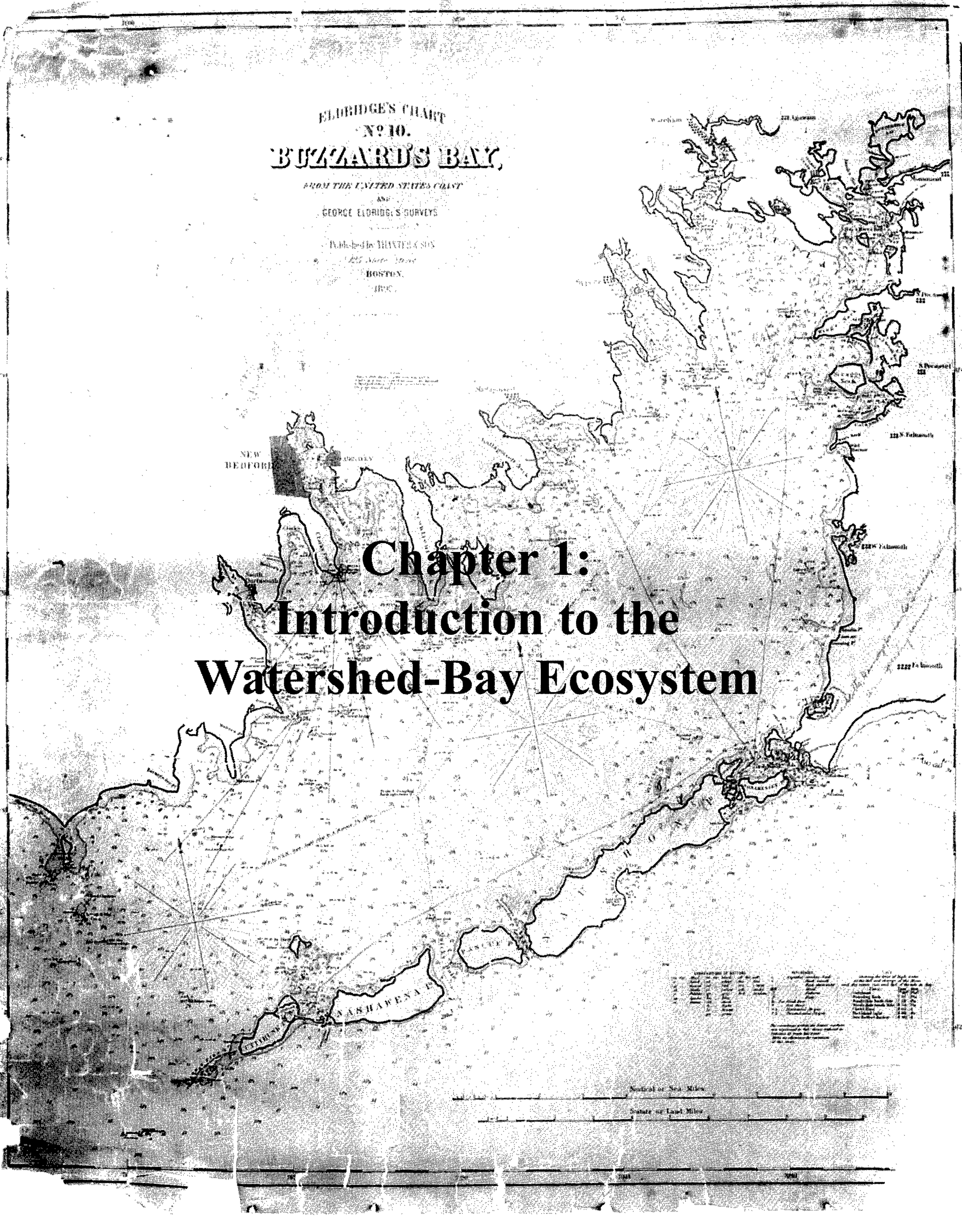
Key words: Buzzards Bay, estuarine ecology, ecosystem, watershed

Chapter 1: Introduction to the Watershed-Bay Ecosystem



1.1. Description

Buzzards Bay, which separates most of Cape Cod from the mainland, is located at a strategic transition point for habitat distribution of many marine species, being proximate to and exchanging with three very different marine systems, the Atlantic Ocean to the south, Vineyard Sound to the east, and Cape Cod Bay to the north (Fig. 1.1). At its northeastern end, Buzzards Bay is connected to Cape Cod Bay by the Cape Cod Canal. The construction of this canal in 1914 allowed ships navigating along a popular trade route from northern to mid-Atlantic and southern ports to avoid approximately 105 to 161 km of treacherous waters off of the outer coast of Cape Cod.

The mouth of Buzzards Bay opens up to the continental shelf east of Rhode Island and Rhode Island Sound, providing access to some of the world's most productive offshore fishing grounds, notably George's Bank. New Bedford, the primary port on Buzzards Bay, still ranks as a major fishing center, registering the second most valuable fisheries landings in the United States in the 1980's. Buzzards Bay itself supports varied fish populations, both resident and migratory, with over 200 recorded species and productive coastal fisheries. In fact, even the name "Buzzards Bay" indirectly reflects the fisheries resource, as it was ostensibly named after the osprey or fish-hawk (*Pandion haliaetus*) (Strother 1860; Kimball 1892). Feeding exclusively on fish, the osprey was known in early natural history as the buzzardet (little buzzard) and was common around the bay (in fact, even noted in Gosnolds voyage). Whether due to the buzzardet or simply the misidentification of osprey as buzzards, the name Buzzards Bay has supplanted the original "Gosnolds Hope." With the recovery of osprey populations stimulated by the banning of dichlorodiphenyltrichlo- roethane (DDT) and the expansion of safe nesting platforms (most notably along the Westport River and Martha's Vineyard; Poole 1989), Buzzards Bay may again warrant the name.

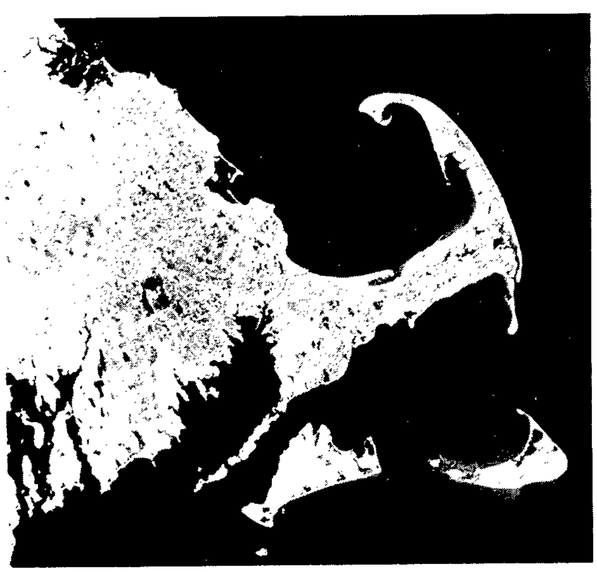


Fig. 1.1. Satellite photograph of Buzzards Bay and Cape Cod.

The long axis of the bay runs northeast to southwest, encompassed primarily by the Massachusetts mainland to the west, Cape Cod to the east and northeast, and the Elizabeth Islands (Cuttyhunk, Nashawena, Pasque, Penekise and Naushon) to the southeast. The bay is approximately 45 km long and 12 km wide. The bay was formed as a result of the last ice age and the retreat of the glaciers (about 16,000-18,000 years before present (B.P.); Kaye 1964; Oldale 1992), and the geologic processes generated lasting differences in the contours of the western versus the eastern shores. The northwestern and northern shores of Buzzards Bay are physically more irregular, creating more embayments than on the eastern and southeastern shores. This undulating coastline encompasses about 336 km after taking into account all the irregularities (Massachusetts Department of Environmental Quality Engineering 1975). The northwestern shore has elongated inlets formed from drowned valleys cut into outwash plain, while the southwestern shore is relatively smooth, consisting primarily of glacial till as part of the Buzzards Bay recessional moraine. The bay itself is relatively shallow; depths range from 5 to 10 m at mean low water (MLW) near the head to slightly over 20 m near the mouth, with a baywide average of 11 m (Signell 1987).

Buzzards Bay supports a wide variety of coastal habitats including tidal wetlands, eelgrass beds, tidal flats, barrier beaches, rocky shores, and tidal rivers and streams. In addition, the joining of Buzzards Bay and Cape Cod Bay via the Cape Cod Canal provides the potential for mixing of semi-tropical and arcadian species, making the bay a unique area for study of marine organisms. The ecological variety of the bay itself as well as its proximity to a number of different marine environments (bay, sound, open ocean) inspired the location of several major marine research institutions in the village of Woods Hole, near the southeastern end of the bay (Fig. 1.2). The Woods Hole Oceanographic Institution and Marine Biological Laboratory are well-known marine research facilities that have taken advantage of the unique range of environments found in this region, as have branches of the National Marine Fisheries Service of the National Oceanographic and Atmospheric Administration (NOAA) and the U.S. Geological Survey. Near the head of the bay, the Massachusetts Maritime Academy trains men and women in the merchant marine field. The quality of the marine waters led Spencer Baird in 1971 to seek establishment of the U.S. Fish Commission (now the National Marine Fisheries Service) in Woods Hole adjacent to Buzzards Bay, when many other mid and north Atlantic coastal areas were showing evidence of pollution from cities or high turbidity from sediment input.

Fig. 1.2. Aerial photograph of research institutions in the village of Woods Hole, Falmouth, Massachusetts.

The watershed area of Buzzards Bay is divided among 10 coastal towns located from Westport on the west to Gosnold on the east (Figs. 1.3 and 1.4) and 8 noncoastal towns, which either completely (Carver, Rochester, Acushnet) or partially (Fall River, Freetown, Lakeville, Middleborough, Plymouth) lie within the watershed boundary. The drainage basin encompasses 1,104 km^2 compared with 550 km^2 of bay surface (Table 1.1). Buzzards Bay is a moderate-sized estuary compared with other systems such as Chesapeake Bay, San Francisco Bay, or even Delaware Bay with watersheds 150, 140, and 30 times the area, respectively, and 21, 2.3, and 3.4 times the water surface, respectively, of Buzzards Bay. Buzzards Bay differs somewhat from other major estuarine systems in that the water surface represents a large portion, almost one-third, of the total area of the bay plus watershed. This potentially decreases the role of inputs from the watershed compared with other large estuarine systems where the bay area is generally less than 10% of the total system

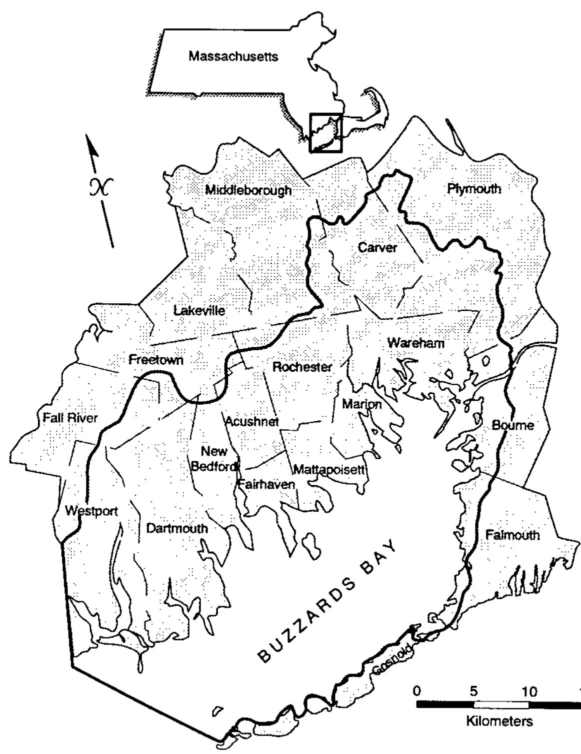


Fig. 1.3. Towns of the Buzzards Bay watershed region.

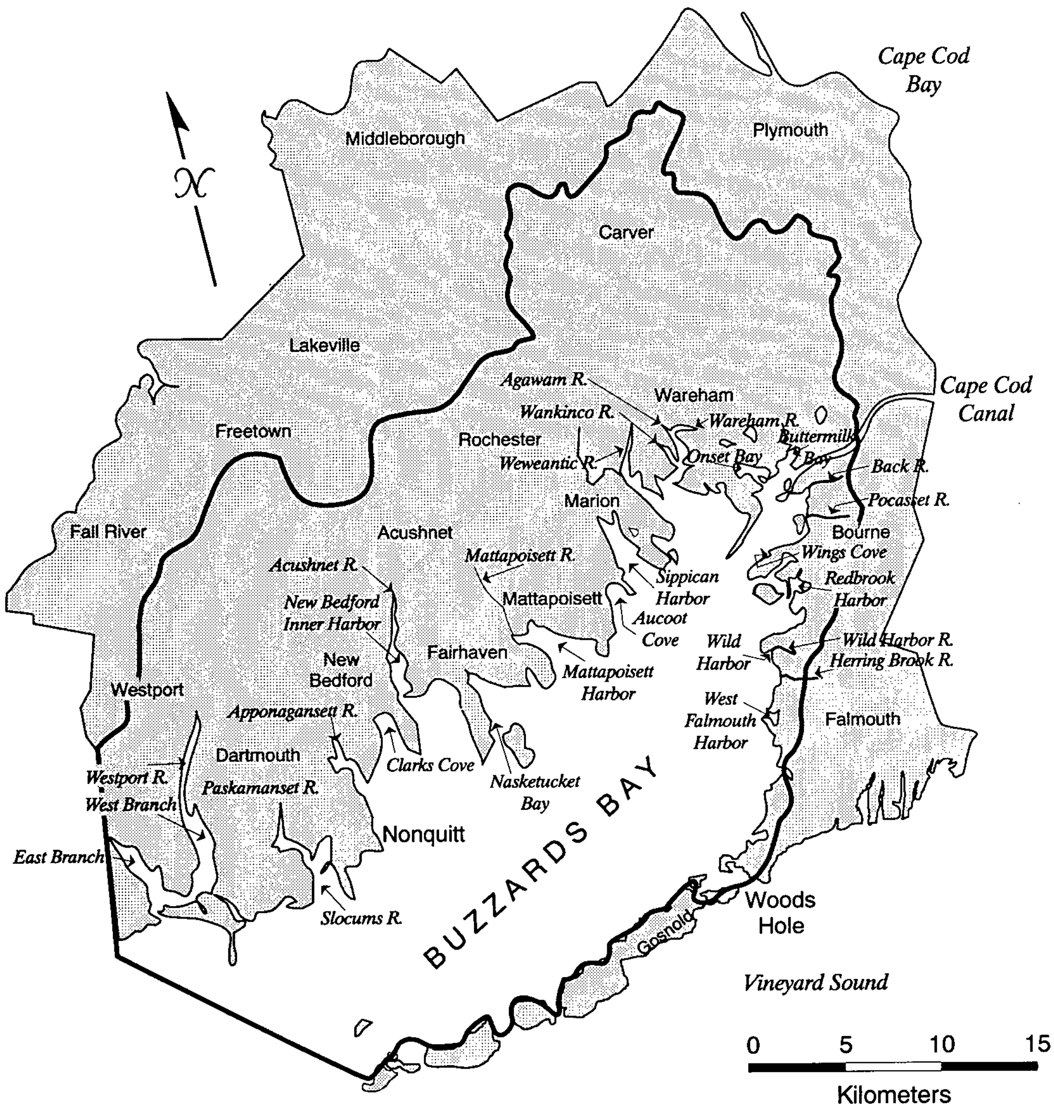


Fig. 1.4. Rivers and harbors of the Buzzards Bay system.

(Table 1.2) and is a partial reason for the high water quality of the bay.

While Buzzards Bay has a water surface of about 550 km^2 it is functionally divided between open water (i.e., the central bay area, 476 km^2) and 27 major embayments (75 km^2) (Table 1.3). The embayments, because of their location and physical structure, are the areas first subject to coastal eutrophication; embayments have restricted circulation and smaller volume for dilution of nutrient inputs from land. Most of the eelgrass (*Zostera marina*) beds and bivalve stocks are located in nearshore areas and embayments less than 5 m deep. In fact, about 3% of the "water" portion of the bay is actually tidal flat. The bay itself is relatively shallow with a mean depth of 11 m and a relatively uniform basin.

The "terrestrial" portion of the system supports some significant salt marsh areas (for New England) primarily on the western shore. The overall ratio of bay surface to salt marsh is about 25, but in the isolated embayments (e.g., Westport) the ratio is less than 3. Most of these wetlands remain "healthy," functioning as nutrient transformers and spawning and nursery grounds for fish and shellfish populations.

Table 1.1. Physiographic features of the Buzzards Bay system.

Feature	Area/ dimension	Source[a]
Watershed area (total)	1104.0 km^2	1
Land surface	1048.5 km^2	1
Water (lakes, ponds, etc.)	28.3 km^2	1
Barrier beach	6.3 km^2	2
Salt marsh	20.9 km^2	2,3
Bay surface area (total)	550.0 km^2	4
Open water	475.4 km^2	
Embayments	74.6 km^2	5
Tidal flats[b]	17.9 km^2	2,6
Bay dimensions		
Length	45.0 km	4
Width	12.0 km	4
Mean depth	11.0 km	4
Volume	6.1 x 10^9 m^3	4

[a]1, SAIC 1991; 2, Hankin et al. 1985; 3, Buzzards Bay Project 1990; 4, Signell 1987; 5, Aubrey Consulting Inc. 1991; 6, modified for Falmouth area in watershed.
[b]Tidal flat area has not been subtracted from open water or embayment areas.

Table 1.2. Watershed and surface area of representative North American bays.

Bay	Watershed area (km^2)	Surface area (km^2)	Ratio: watershed/ bay
Chesapeake Bay[a]	166,000	11,400	15
San Francisco Bay[b]	153,000	1,240	123
Delaware Bay[a]	33,000	1,870	18
Narragansett Bay[c]	4,613	427	11
Buzzards Bay[d]	1,104	550	2

[a]Bumpus 1973.
[b]Conomos et al. 1985.
[c]NOAA/EPA 1989.
[d]Buzzards Bay Project 1989.

Table 1.3. Dimensions of the major embayments of Buzzards Bay. Adapted from Costa et al. 1994.

Embayment	Surface area (km^2)	Length (m)	Width (m)
Acushnet River	10.7	12,050	2,000
Allens Pond	0.8	3,740	180
Apponagansett Bay	2.9	5,710	940
Aucoot Cove	1.3	1,280	1,020
Brant Island Cove	0.3	1,340	360
Buttermilk Bay	2.2	3,800	960
Clarks Cove	2.9	2,380	1,270
Hens Cove	0.3	2,650	410
Marks Cove	0.4	1,230	410
Mattapoisett Harbor	4.3	5,690	1,880
Nasketucket Bay	2.1	2,640	1,320
Onset Bay	2.4	3,910	760
Phinneys Harbor	2.2	2,770	1,220
Pocasset River	0.8	1,520	510
Quissett Harbor	0.5	1,170	410
Red Brook Harbor	0.6	2,140	810
Sippican Harbor	7.5	8,660	1,140
Slocums River	2.0	5,440	330
Squeteague Harbor	0.3	1,120	410
Wareham River	2.5	3,050	560
West Falmouth Harbor	0.8	1,520	410
Westport River			
East Branch	8.0	14,630	1,070
West Branch	5.3	8,350	810
Weweantic River	2.4	3,860	460
Widows Cove	0.5	1,170	510
Wild Harbor	0.5	810	560
Wings Cove	0.9	1,690	660

Eleven small primary rivers empty into the bay; seven are found on the western shore: Agawam, Wankico, Weweantic, Mattapoisett, Acushnet, Paskamanset, and Westport, and four on the eastern shore: Pocassett, Back, Wild Harbor, and Herring Brook (Fig. 1.4). All are tidal to some extent inland from their mouths, and the eastern shore rivers are primarily groundwater fed. The river discharges on different sides of the bay reflect the very different watershed areas available for generating freshwater flows as well as the effects of their differing glacial history on surface versus groundwater flow. Inputs of freshwater discharges directly into the bay are relatively small compared to the daily flushing of seawater, and subsequent minor dilution of salinity results in bay water salinity concentrations approximating that of nearby oceanic waters. The salinity results from the relatively small (2:1)

watershed versus bay area (Table 1.1) and heightens the contrast between the embayments, which have more estuarine habitat, and the almost marine open bay.

Like many of the developed areas of the eastern seaboard, Buzzards Bay has experienced high rates of population growth with increases of more than 50% over the past 50 years. As of 1990, this watershed supported a population of 233,000, or roughly 2.1 people per hectare. While this is a moderate density, the recent increases have been dramatic. Some towns have grown from small rural communities to suburban communities for Boston or Providence; others have experienced continued growth in response to the demand for summer or retirement homes near the water.

1.2. History

Buzzards Bay was highly regarded as a resource to the early settlers of the region. In fact, many of the early uses of the watershed and bays remain: farming and cranberry agriculture, fishing, shellfishing, and even some haying of salt marsh grasses.

Colonists living in Plymouth saw Cape Cod as both a blessing and a hindrance: a blessing in that it provided trade with the Native Americans who inhabited the cape, but a formidable hindrance to trade with the Dutch residing in New York (then called New Amsterdam). Navigating the treacherous waters around Cape Cod discouraged many otherwise profitable voyages. Shortly after the establishment of a permanent colony at New Plymouth in 1620 and the Massachusetts Bay Colony in 1628, a simpler route was discovered. This passage utilized two nearly connecting rivers and a portage across a narrow strip of land separating the head of Cape Cod Bay from Buzzards Bay (a passage long used by the Indians) and greatly facilitated trade among the colonists between Plymouth, the Connecticut River, and New York. The establishment in 1627 of the Aptucxet Trading Post (or Manomet Trading Post, located on the river of the same name emptying into Buzzards Bay) attracted many visitors and subsequently new settlers to the area. This post, situated near what is now the west end of the Cape Cod Canal, provided a station for trade of goods between the Dutch, the settlers of New Plymouth, and the resident Wampanoag Indians.

The first established town on Cape Cod, the Town of Sandwich (1639), originally incorporated what is now the coastal town of Bourne on Buzzards Bay. West Falmouth, bordering the bay, was home to many Quakers who settled there to flee persecution by the Plymouth Court. This area was known at the time as "Suckanesset" (today called Saconnesset), named by the Native Americans as "where the black wampum is found" (Emery 1979:4). Beads made from quahogs were used as a form of currency, known as "wampum," and from this use the species name of quahog (*Mercenaria*) was derived. Wampum from the shells of the quahog was twice as valuable as the wampum made from the shell of the periwinkle. Many Native Americans lived on the shore of West Falmouth as evidenced by the large number of Indian relics and grave sites uncovered there in recent years. These Indians were generally cooperative and helped many settlers adapt to this new area, taking advantage of the abundance of natural resources the bay provided.

Although the original settlers of this region were primarily farmers, the abundance of the sea rapidly encouraged a healthy fishing industry in the late 1600's. Even in the few days Gosnold spent on the bay in 1602, landing in present day Gosnold and then entering Buzzards Bay, which was then called "Gosnolds Hope," it was clear that "diverse sorts of shellfish as scallops, mussels, cockles, lobsters, crabs, oysters and wilks (sic. *Mercenaria*) exceeding good and very great" were available (Brereton 1602:29). In support, Capt. John Smith's *Description of New England* (1616), although praising the soil and climate for agriculture, particularly noted the fishing. This still seemed the case when Thoreau visited in 1849 and 1855, observing "the inhabitants of the Cape are often at once farmers and sea rovers" (Thoreau 1966:162). This

statement represents the full system utilization that continues, except that residential development began supplanting farming as the major nonurban land use, and much of the farmland of Thoreau's day is now reforested (currently 61% of the land is forested).

In the 1600's and 1700's major uses of the bay-watershed were, as stated, related to farming and fishing. The bay not only provided harvest but was also the major mode of transport, especially given the sandy roads of the region. Farming was on a relatively small scale, primarily for subsistence, through the 18th century. Corn was the principal crop and served not only as a source of food but also as currency. Wheat was not prevalent as it did not grow well and suffered from mildew; however, rye was successfully grown along with onions and beans. Sheep were especially important during this early period as they provided both mutton and wool for clothing that "made up in durability what they lacked in grace" (Kitteridge 1930).

Standing at the land and sea interface, the salt marshes of Buzzards Bay provided for major exploitations of farming and fishing. These marshes were used throughout New England as a source of the salt marsh hay, *Spartina patens*. Marsh haying was important to early settlers as the economy of the region was largely dependent on animals. The abundance of salt hay provided a ready source of food and fodder for oxen, horses, cattle, and sheep. Salt hay was also used as packing material and insulation for the "ice houses." After years of common ownership, the marshes were divided up into private ownership, bought and sold much like house or wood lots. Salt haying along Buzzards Bay progressively diminished with increased availability of cultivated hay from inland areas and largely stopped after the "Portland Storm" in 1898. Ice rafting during this major winter storm destroyed most of the posts, known as hay staddles, upon which salt hay was set to dry above the flooding tides. In recent times the high quality of salt hay as a garden mulch, relatively free of weed seeds, has renewed demand.

The watershed was deforested by the 18th century by the combined effects of agriculture and the need for wood for cooking and heating as the population grew. The uncut forested watershed observed by Gosnold survives only in isolated patches. Substantial amounts of wood were also cut to fuel fires for the production of salt through evaporation of seawater, an important local industry providing salt for the curing of the abundant fish collected from nearshore and offshore waters. In 1863 a fertilizer factory based on the use of fish was established in Woods Hole, with Buzzards Bay to supply much of the required menhaden (*Brevoortia tyrannus*) (the 9,072 t annually required was more than could be caught from the bay alone, however, so it was supplemented by catch from other waters) (Fawsett 1990).

Unlike in Cape Cod Bay, there are no reports of the occasional pilot whale beachings on Buzzards Bay shores, which provided a safer and easier source of whale products for the local residents. The larger-scale commercial whaling industry from the early to late 1800's, however, was a bay-wide enterprise with whaling ships being built in or sailing from New Bedford on the west, Woods Hole on the east, and Wareham at the head of the bay. The substantial profit to be gained from whaling encouraged many sea captains to settle in the towns around the bay. Baleen, being strong but elastic, was a valuable commodity for corsets, fishing poles, and the like. Even more important was the harvest of all species of whales for their oil. Whale oil was highly prized for lamps, and the waxy residue from processing of this oil, known as "spermacetti" (sperm whales supply the purest and largest quantities of oil), was equally valuable for making wax candles. These candles burned twice as long as traditional candles made from mutton, beef, bear, or deer fat; in fact, the pure flame given off by spermacetti candles was long used as a standard measure for artificial light. "One candle-power" was identified as the amount of light given off by one pure spermacetti candle weighing 28 g.

The demand for spermacetti resulted in the construction of a candle house in Woods Hole in 1836, at the height of the whaling industry. Woods Hole, a village of Falmouth, was already an important seaport, and although much smaller than the other seaports of New Bedford, Provincetown, Truro, and

Wellfleet, its deep waters were attractive as a home port to many whaling ships. Even at its height, however, Woods Hole was not nearly as important as New Bedford to the whaling industry. Not only regionally prominent, New Bedford was known as the "Whaling Capital of the World" and the country's greatest whaling port from 1820 until the Civil War. In 1845 alone, 150,000 barrels of sperm oil, 272,000 barrels of whale oil, and three million pounds of whalebone were brought in by the 10,000 seamen on New Bedford ships (Fawsett 1990).

Coincident with the growth in whaling was a growth in commercial fishing in Buzzards Bay, notably for menhaden and mackerel (*Scomber scombrus*) during spring and summer months. By the late 1800's commercial fishing and catch information were entering the "modern" era with operations of the U.S. Fish Commission and advancements in fishing technology. Buzzards Bay fisheries have changed significantly, with Atlantic mackerel (pre-1920) and scup (*Stenotomus chrysos*; post-1960) accounting for about half the total commercial catch (Buzzards Bay Project 1987).

In the early 1900's weirs (fish traps) were used along the shores of Buzzards Bay. The weirs were used for catching species not typically caught by draggers like bonito (*Sarda sarda*), scup, and butterfish (*Peprilus triacanthus*; Bowles and Livingston 1981). Weirs were made by sinking numerous upright poles into the sediment and stringing them with netting, making a long, wide extended opening to guide fish into the base or bowl of the trap. After the disruption to industry as a result of the Civil War, weir fishing began to grow in popularity as it enabled many fishermen to work the local shallow waters without the hazards of deep sea fishing. Catch by weir fishing is generally quite variable with no guarantee of marketable catch; however, many local fishermen during this period were able to switch from deep sea to local waters without serious loss in income (Fawsett 1990). Also during this time, attention turned toward the shallow shellfisheries, which provided a reliable source of income with a smaller investment in equipment. Lobstering and clamming grew in popularity along with the seasonal scallop industry.

With the growth of whaling and fishing came a large increase in supporting maritime trade industries. Farming gave way to marine-based economies in towns like New Bedford, Woods Hole, Fairhaven, and Padanaram (a village of Dartmouth), and they experienced a surge in the growth of trades to support the sea-based industry. Boat builders, blacksmiths, coopers, sail makers, carpenters, and so forth settled in these areas along with a large number of unskilled laborers. However, the availability of kerosene in the 1860's brought about a swift decline in the whaling industry. Coincident with this decline was the development of the cotton manufacturing industry in the northeast, taking advantage of the availability of workers and water power and shifting the major industry toward manufacturing (Fawsett 1990). New Bedford and Fall River, with their protected waters, proximity to offshore fishing grounds, and extensive growth, have continued to be the industrial centers within the Buzzards Bay watershed. Early this century large urban populations forced New Bedford and adjacent Fairhaven to handle sewage through centralized wastewater treatment plants and to construct outfalls into Buzzards Bay. Hence, the inner and outer harbor regions of New Bedford represent the major industrial and nutrient point sources of pollution for the entire bay, with most of the remainder of the region having farming, light industry, and nonpoint (septic) disposal of wastewater as the main pollution concerns. This pattern continues today. Historically, the primary toxic pollutants were from textile (dyes), metal fabrication and jewelry (metals), and (more recently) electronics industries (PCB's) (Camp, Dresser, and McKee, Inc. 1990; Terkla et al. 1990).

1.3. Present Day

The fishing industry continues to be an important economic resource for Buzzards Bay. Although commercial finfishing has been prohibited in the bay since the late 1800's, a relatively large fishing fleet supported by ports such as New Bedford and Woods Hole fishes George's Bank for Atlantic cod (*Gadus morhua*), mackerel, haddock (*Melanogrammus*

aeglefinus), striped bass (*Morone saxatilis*), winter flounder (*Pleuronectes americanus*), and the like as well as ocean scallops (*Placopectin megellanicus*). More locally, shellfishing (primarily bay scallop (*Aequipectin irradians*) and quahog) was and continues to be an important industry throughout the bay ($4.5 million in 1988), with additional commercial and recreational harvest of soft-shelled clams (*Mya arenaria*) and lobster (*Homarus americanus*). However, overfishing and the ever-increasing shellfish bed closures because of coliform contamination put a growing strain on this industry as an economic resource (S. Cadrin, Massachusetts Division of Marine Fisheries, personal communication).

The exception to the modern day decline in agriculture within the watershed is cranberry growing. Cranberries were harvested around Buzzards Bay by Native Americans and later by European colonists. With the cultivation of cranberries and development of cranberry agriculture came both increased yields and the construction of extensive cranberry bogs, usually by converting freshwater wetlands (Thomas 1990). At present, cranberry agriculture yields 30 times more revenue than the second most important agricultural industry, dairy farming, and employs 12 times the workers (Terkla et al. 1990). Many of the bogs within the Buzzards Bay watershed were originally under cultivation more than a century ago when the watershed accounted for about 25% of the total cranberry production in the United States. The wetland nature of many of the bogs, which are located on streams and rivers emptying into Buzzards Bay, makes management of this fertilized agriculture potentially significant to managing the nutrient-related water quality of the bay (Howes and Teal 1992).

The value of Buzzards Bay and the Cape Cod Canal to the shipping industry is almost incalculable, not only for the direct economics of transport in shortening the circuitous route around Cape Cod but also for the savings in countless lives and ships. As in the colonial era, the bay continues to serve as a major transportation system. Traffic through the bay today consists primarily of oil tankers, freighters, and barges carrying over 17.2 million t of commercial cargo and much of the refined oil for New England. More than 6,300 large cargo vessels pass through the canal each year, as well as more than 25,000 smaller vessels, including fishing and pleasure boats, many of which would be ill-equipped for the long and dangerous voyage around Cape Cod (Farson 1993).

One of the primary uses of Buzzards Bay today is as an aesthetic and recreational resource. The many small coves, inlets, and harbors around the perimeter of the bay provide shelter for numerous boat moorings and many types of recreational activities, from boating, fishing, sailing, and swimming to other water sports such as scuba diving and water skiing. The high level of water quality generally found within the bay attracts a large number of tourists each year to its shores, providing an important economic resource to many of the local communities. The active recreational fishery in Buzzards Bay provides both direct income to the local marine industries and indirect support for the tourist industry.

The major alteration in land use within the Buzzards Bay watershed over the past century has been the shift from farming to residential housing, primarily post-World War II. The major urban center, greater New Bedford, has maintained a nearly constant population since 1930, a result of the major expansion in population due to the whaling industry in the 1800's and the city's growth as a manufacturing center (Terkla et al. 1990). In recent years, regional changes have been primarily related to suburban growth, particularly in the tourism and retirement populations (Fig. 1.5). The result is that the nonurban population has now surpassed the urban population, as was the case 200 years ago.

After almost 400 years of recorded development, many of the activities within the bay-watershed system remain essentially the same although, of course, technologically advanced in practice. Fisheries and agriculture remain essential resource uses, but, as in many other systems, the fisheries yields have diminished due either to overfishing or alterations in habitat. The major shift of emphasis has been from farming to residential and tourist

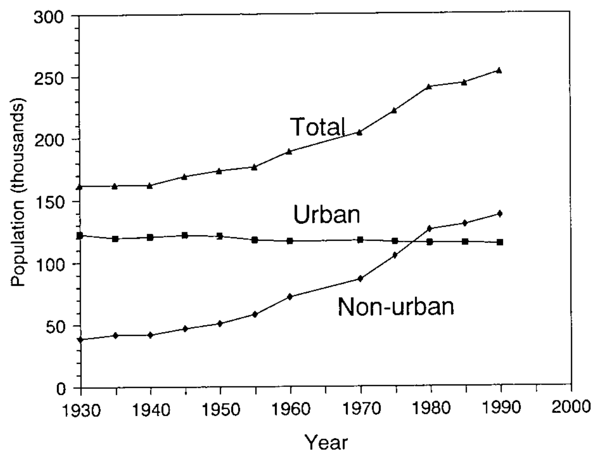
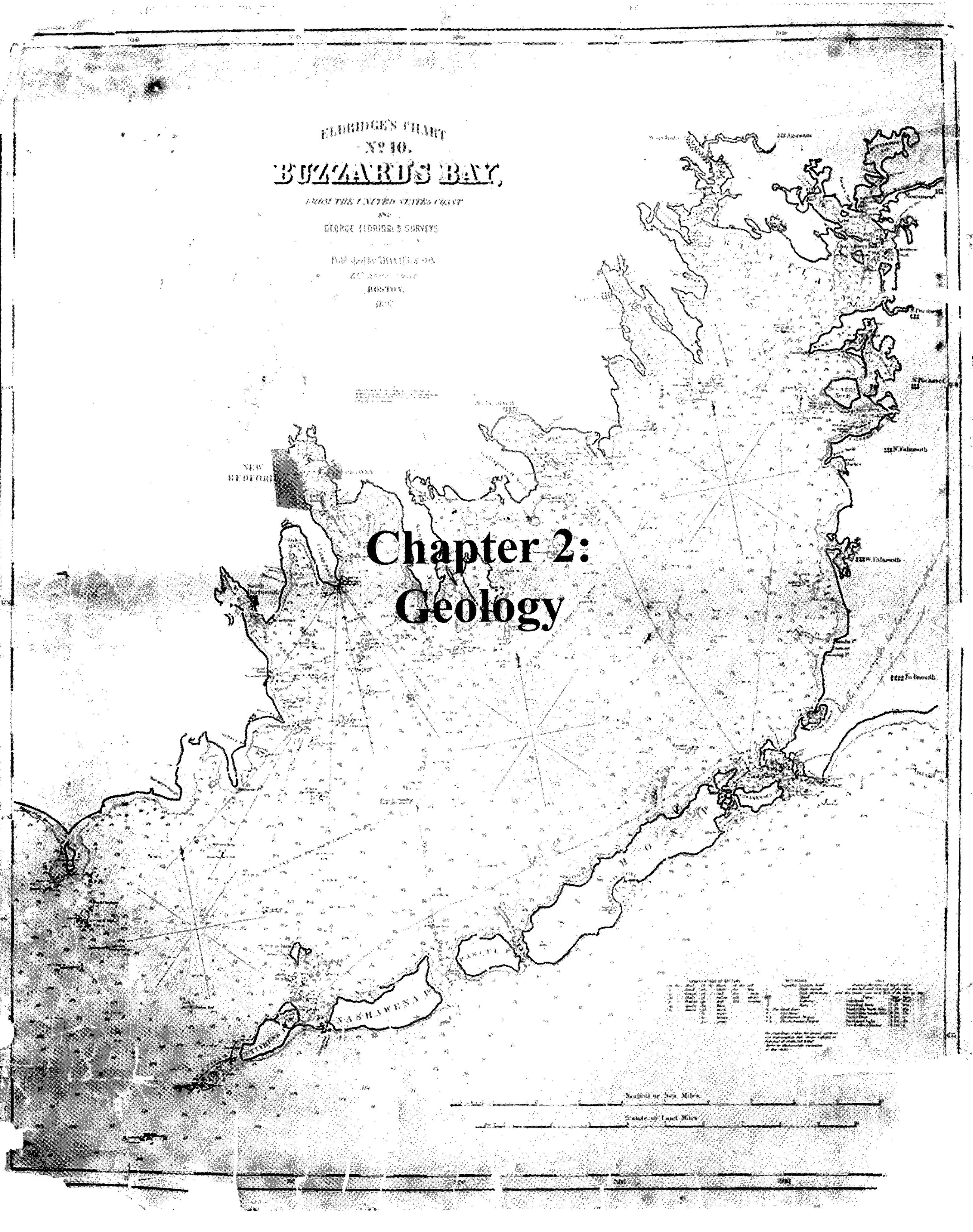


Fig. 1.5. Urban and non-urban population growth in the Buzzards Bay watershed.

related development, and the increased population and its concomitant increase in nutrient loading to bay waters may for the first time represent a significant threat to the productivity and diversity of this ecosystem.

Chapter 2: Geology



Buzzards Bay and its surrounding uplands represent a relatively young coastal feature in New England. While the basic structure of the system was created by glacial transport and subsequent erosion of sediments during glacial melting and retreat, secondary processes of relative sea-level rise, wave and tidal erosion, and sorting and transport of sediments continue to transform both the land-sea margin and the subaerial portion of the bay.

2.1. Formation

Buzzards Bay was formed by processes associated with the Laurentide Ice Sheet which, centered on Labrador and Hudson Bay during the final or Wisconsin Stage of the Pleistocene Epoch, started some 50,000-70,000 years B.P. Before the Cape Cod region was glaciated, there was an extensive coastal plain consisting of Tertiary and Cretaceous rocks that extended seaward to the approximate location of present day Nantucket, Martha's Vineyard, and Block Island. The land surface graded downwards toward the ancient shoreline (Hough 1940). Pleistocene glaciation, specifically the Buzzards Bay, Cape Cod Bay, and South Channel lobes (Fig. 2.1), modified this surface and to a lesser extent the adjacent and underlying New England Oldland. The advance and retreat of these three lobes, formed because of variations in the speed and movement of the edge of the Laurentide

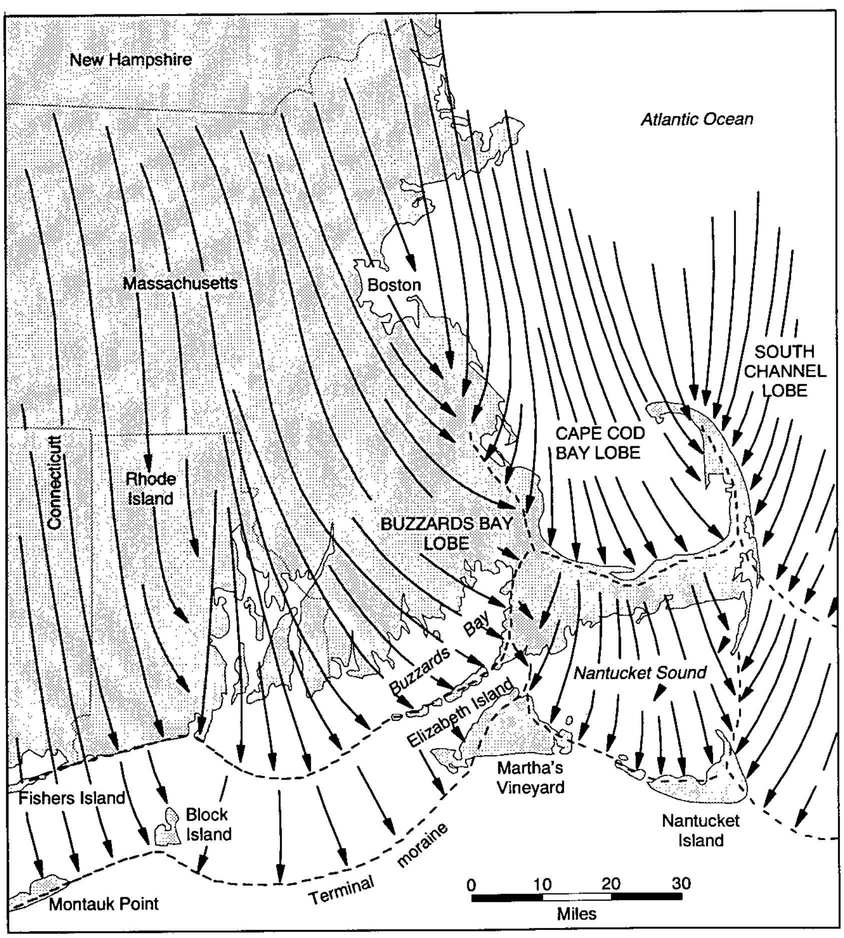


Fig. 2.1. Southern New England showing the directions of flow of ice of the Wisconsin Stage (by arrows) and the two positions of ice standstill (dashed lines). From Strahler (1966).

Ice Sheet, were responsible for the formation of Cape Cod, Nantucket, Martha's Vineyard, and Buzzards Bay and its watershed.

The structure of the Buzzards Bay estuarine system is most closely linked to the Buzzards Bay lobe (as it was modified by the Cape Cod Bay and South Channel lobes). The Buzzards Bay lobe initially spread across the area of Buzzards Bay to its farthest extent at western Martha's Vineyard. At this point the advance halted for a period of more than 1,000 years during which glacial till was deposited as ice continuously arrived but melted or evaporated before it could advance the perimeter. This till consisted not only of soil and decomposed rock but also of bedrock collected by the ice as it flowed southward across New England. During this stationary phase a portion of the terminal moraine of the Buzzards Bay lobe was deposited (Fig. 2.1). A series of events followed that made the formation of the moraines of the Cape Cod and Islands region different than most moraine formations throughout the United States (Oldale 1992). After the period of melting and retreat, the glacier readvanced over the heavier deposits nearest the glacier face and acted like a bulldozer, lifting layers of the glacial deposits and some previous surface material and thrusting them forward in a process called "glacio-tectonics." In the final phase, the margin of the Buzzards Bay lobe overrode the thrusted deposits and when it melted left a thin veneer of glacial till covering the thrusted deposits that form the terminal moraine (Oldale 1992).

Sloping away from the moraine is an outwash plain deposited as the finer materials were carried away from the ice edge in meltwater flows. Sloping led to a gradation in sediment sorting and elevation moving away from the moraine. Indeed, today the highest elevations in the Buzzards Bay watershed and Martha's Vineyard (30.5-61 m) are associated with the Buzzards Bay lobe morainal deposits. Radiocarbon dating (Kaye 1964) suggests that sometime after 15,300 - 800 years B.P. climatic warming caused the Buzzards Bay lobe to rapidly retreat to what is approximately the eastern watershed boundary for Buzzards Bay and the Cape Cod Bay lobe to the location of the Sandwich moraine (Larson 1980). This secondary position of the ice margin was held for a period, and moraines were formed by glacio-tectonic processes and, to a lesser extent, glacial till from the continual inflow and melting of ice (Strahler 1966; Oldale 1992). Thus the relatively large Buzzards Bay (and similarly the Sandwich) moraine was formed, 1.6-3.2 km wide and extending within the watershed from the Elizabeth Islands to the head of the bay. The Cape Cod portion is surrounded by outwash on both sides in its northern parts and is relatively high at 30.5-61 m. The Elizabeth Islands portion is of relatively low relief, generally less than 12.2 m with a maximum of 36.6 m. These islands consist entirely of glacial debris with eroded boulders from the moraine forming a natural rip-rap in the face of advancing sea level (Moore 1963) and providing a rocky substrate for colonization by biotic communities. Between the Buzzards Bay and Sandwich moraines, the Mashpee pitted outwash plain was formed, making up much of this portion of Cape Cod (Fig. 2.2).

Further retreat of the Buzzards Bay lobe across current Buzzards Bay to approximately the western watershed margin, coupled with minor readvances, led to smaller moraines, outwash plains, and glacial till deposits on the western shore. The elevation of the terminal and recessional moraines with outwash plain sloping away helped to determine the watershed of the existing bay. The meltwater eroded the outwash plain and generated outwash channels that were later flooded by rising sea level to create the many embayments on the western side of the bay and similarly outside the watershed on the southern shore of Cape Cod on the Mashpee pitted plain (Fig. 2.2). In addition, the presence of outwash adjacent to the shorefront tends to result in sandy-or fine-grained sediment bottoms whereas erosion of moraine leads to a rock- and boulder-strewn coast. These substrate conditions laid down by glaciation thousands of years ago continue to affect benthic biotic structure today.

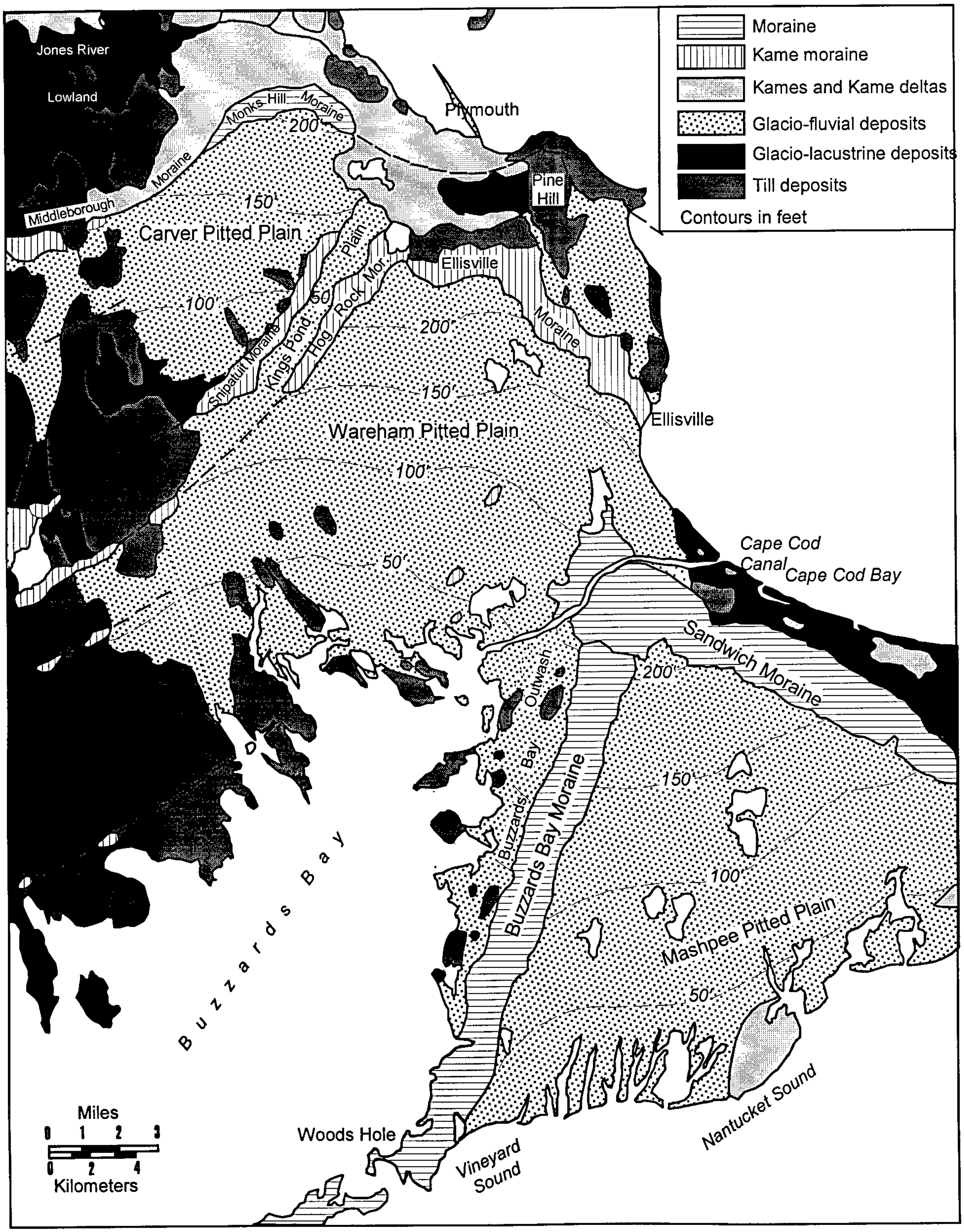


Fig. 2.2. Glacial geologic map showing end moraines and sandurs of the Plymouth-Buzzards Bay area of southeastern Massachusetts. From Larson (1980).

The retreat of the two adjacent glacial lobes did not occur in concert. The Buzzards Bay lobe and the Cape Cod Bay lobe met approximately at the location of the Cape Cod Canal. The Buzzards Bay lobe began retreating before the Cape Cod Bay lobe, uncovering a break in the moraine at the point where they joined. With the later melting of the Cape Cod Bay lobe, water was able to flow through the break where the canal is now located, across the outwash, and into Buzzards Bay. In later years, two streams with headwaters less than one kilometer apart inhabited the old glacier outlet, separated by a sandy ridge: the Scusset River flowing northeast into Cape Cod Bay and the Manamet (or Monument) River flowing southwest into Buzzards Bay. No more than 9.1 m above sea level, these valleys became a natural area for later construction of the Cape Cod Canal.

2.2. A Marine Bay

The rapid warming about 14,000 years B.P. that caused the retreat, thinning, breakup, and final disappearance of the ice sheets did not end the ice-driven morphological alterations of the New England surface. When the water trapped in that ice returned to the oceans a relatively rapid rise in sea level occurred. During the past 18,000 to 10,000 years ocean levels rose 60-120 m with levels about 7,000 years B.P. at 7-10 m below present (cf. Emery and Aubrey 1991). In the region of Cape Cod, this rise in sea level resulted in the flooding by Atlantic Ocean waters of Cape Cod and Buzzards bays and Nantucket, Vineyard, and Long Island sounds. As relative sea levels rose, Martha's Vineyard and Nantucket became islands, and the lower deposition between the terminal and Buzzards Bay moraines became the sounds. The lower topography of what became Buzzards Bay is probably a result of a combination of events, starting with subaerial erosion during a period of extremely low sea level in the late Tertiary (Veatch 1906), insufficient deposition (being at the margin of the Wareham pitted plain), and erosion due to meltwaters from the later retreat of the Cape Cod Bay lobe. Whatever the cause, rising sea level flooded current Buzzards Bay about 5,000-6,000 years B.P.

The historic rate of relative sea-level rise (the combination of eustatic or ocean surface rise and changes in the land surface due to subsidence or uplift) can be ascertained by radiocarbon dating of reefs, deltaic deposits, intertidal peats, and so forth. One such study using intertidal peats collected at the peat/till contact was conducted in Barnstable Marsh only 10 km from Buzzards Bay. Since the peat was generated by salt marsh plants, which only grow in intertidal wetlands, it acts as a tracer for historic relative sea level. It appears from this method (Fig. 2.3) that the early rapid (0.003 m/year) rise in relative sea level continued until about 3,500 years

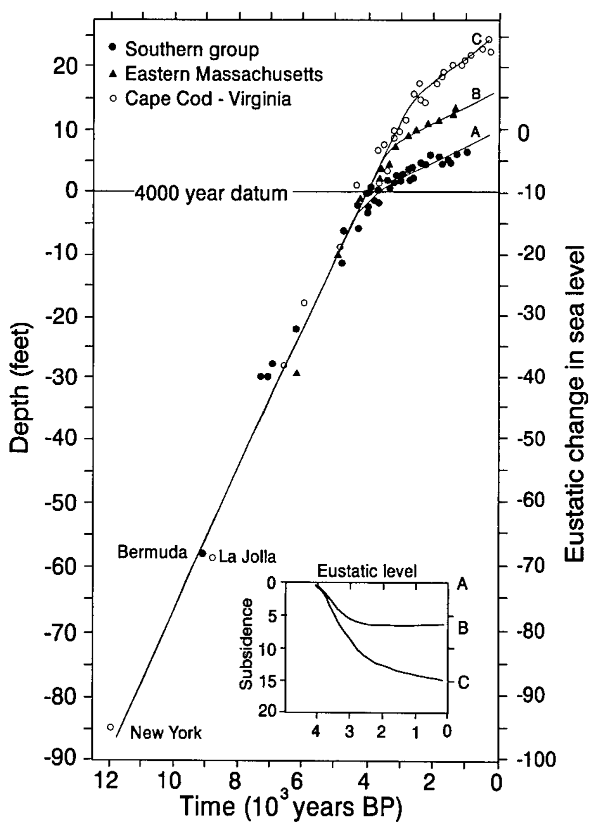


Fig. 2.3. Age of peat at depths relative to the 4000-year B.P. datum. Scale on right shows assumed eustatic rise in sea level. (Inset: Curve B is subsidence of coast of eastern Massachusetts; Curve C is subsidence from Cape Cod to Virginia. Curves A, B, and C correspond to main figure.) From Redfield (1967).

B.P. when the rate of rise slowed markedly. During this initial period almost all of the current main basin (and many of the current embayments) became flooded with sea water. (Recent acceleration in the rate of relative sea-level rise is discussed in Chapter 6.)

Given the relatively uniform depth of the Buzzards Bay Basin (Fig. 2.4) the transition from emergent upland to submerged bay bottom would have probably occurred relatively rapidly (over a few thousand years). Flooding would necessarily have followed the depth contours, which get shallower moving north toward the head of the bay and laterally along the axis toward the western shore. Current bathymetry is smoother than before flooding because of marine deposition in the valleys and holes. Most of the current bay is less than 15.2-m deep, with the exception of Quicks Hole (38.4 m)

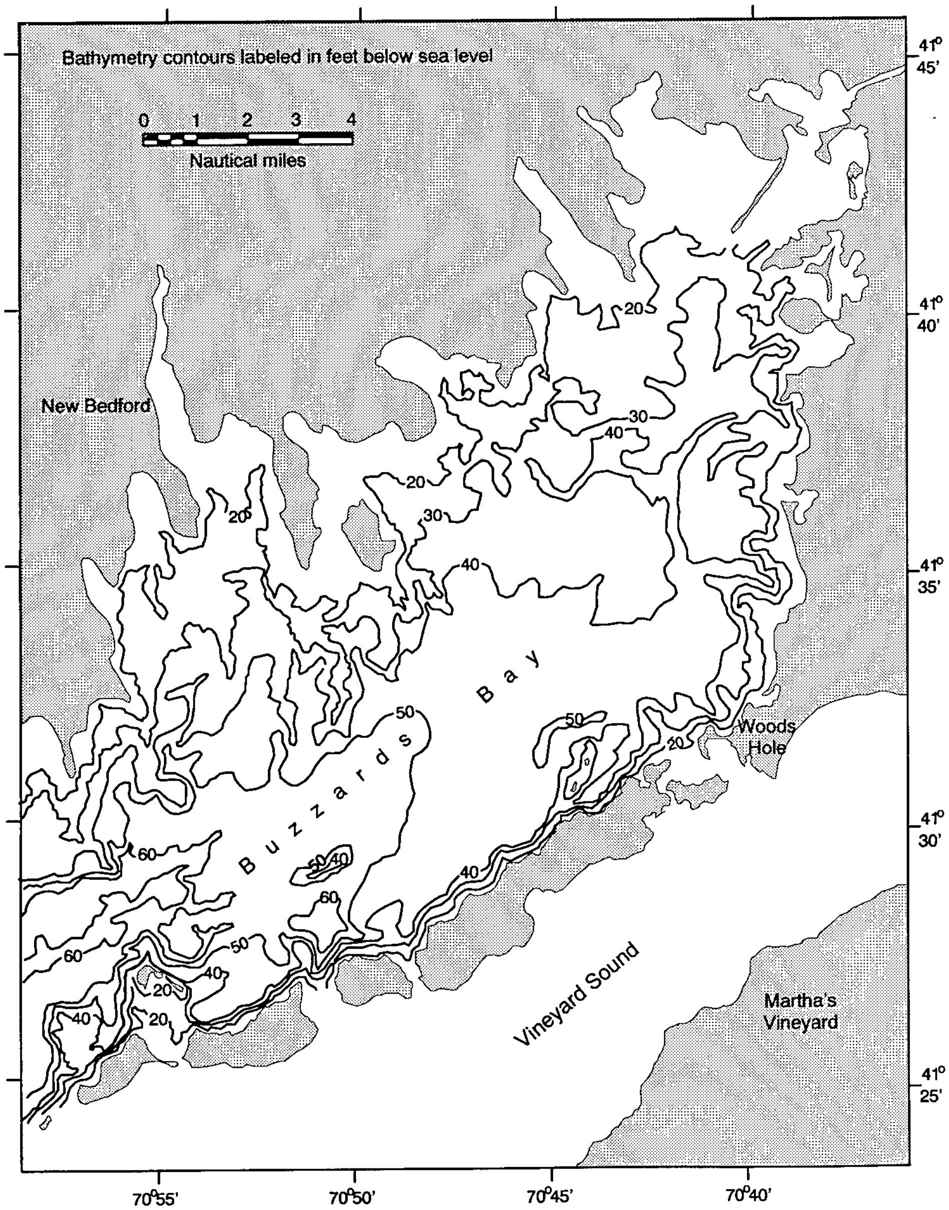


Fig. 2.4. Bathymetric contours of Buzzards Bay adjusted to mean low water datum. From Moore (1963).

and the main channels in the bay mouth (30.5-42.7 m). It has been suggested that the bottom topography reflects glaciation; deep channels in the bay mouth extend into the bay (through shoaling) and continue into the 15.2-m contour and the greatly extended 12.2-m contour toward the bay head. This greater channel structure may reflect late glacial erosion (Hough 1940). To a lesser extent, the outwash channels in the western shore (e.g., New Bedford) continue offshore (Driscoll and Brandon 1973) because of their drowning after formation. Once the flooding of the Buzzards Bay basin commenced, the now subtidal sediments were subject to reworking and transport.

2.3. Sediments of Buzzards Bay

The surficial deposits within the Buzzards Bay watershed appear to be predominately Pleistocene in origin. Although deposits of some pre-Pleistocene sediments have been reported (Woodworth and Wigglesworth 1934), these have not been confirmed. It is therefore thought that the earlier Tertiary and Cretacean strata are not apparent (or active) in the present system (Moore 1963). The texture of the glacial drift is coarse with sand size particles most abundant and with little silt and clay (Hough 1940), and gravels and rocks are common within the moraines. The thickness of the Pleistocene deposits is of course variable, but appears to extend to the bedrock (e.g., Dedham granodiorite). Emery (1969) reported that a subtidal boring in Woods Hole encountered granodiorite at 83 m below mean low water (under 81 m of clean sand and 2 m of water) although basement may be nearer to the surface (47 m) to the northeast (Oldale and Tuttle 1964).

The most abundant rocks in the Buzzards Bay moraine exposed to bay waters in the southern portion are gneiss and granites (Hough 1940; Driscoll and Brandon 1973). The source of these granites appears to be most likely the Dedham granodiorite and associated rocks from the region adjacent to the Boston Basin with apparently some southern Maine diorite and possibly contributions from northeastern Massachusetts. "Thus it would appear that ice moving southward from southern Maine and southeastern New Hampshire across the eastern margin of Massachusetts could have gathered all of the diverse materials found in the Buzzards Bay Moraine" (Mather et al. 1942:1143), and in the recessional moraines as well. On the western shore, in addition to the glacial transport, Dedham grandiorite can been seen in outcrops (Emerson 1917). The glacial drift and to a much lesser extent this exposed granodiorite adjacent to the bay primarily constitute the source of "new" sediments to the bay bottom (Hough 1940; Moore 1963).

The initial source of bay sediments was the same as the surrounding upland until flooding by the ocean, at which time biogenic and water-transported deposits began to form, and reworking and sorting of the sediments began to take place. A minerology study (Hough 1940) found quartz to be the dominant mineral in all samples, and feldspars were second in abundance. The feldsparthic sands are directly related to the erosion of Buzzards Bay system glacial debris. In the deeper waters there is an abundance of clays, micas, fine-grained quartz, and feldspar.

Tidal and wind-driven currents are the most important source of energy for sediment transport and sorting within Buzzards Bay. These currents result from the protection offered by Cape Cod and particularly the Elizabeth Islands, which prevents long-period ocean waves from entering the bay (Moore 1963). In addition to providing a mechanism to alter basin sediments, the flooding of the basin allowed for erosion of shoreline deposits by wave action. To date, erosion of headlands and island shores has cut them back many meters. Coupled with longshore transport, the curvature of the coast has been somewhat reduced, and some embayment openings have been restricted by bay mouth bars and, if shallow enough, have been filled with wetlands (for example, Great Sippewissett Salt Marsh in West Falmouth). Overall, however, the change in the shoreline has been modest due to the abundant boulders in the glacial drift areas, which form a pavement and retard erosion (Hough 1940).

The subtidal basin topography has undergone alterations as well, mainly smoothing (Fig. 2.4) resulting from erosion of shoals and increased deposition in hollows. However, like the beaches, the shoals (formed from the same materials) also form a coarse surface layer slowing their erosion. The major alteration has been the deposition of fine-grained sediments in the central bay, producing a gently sloping bottom (Hough 1940).

Overall, Buzzards Bay is identified as a net depositional area (Camp, Dresser, and McKee, Inc. 1990), with a progression of silts and clays being transported from the outer continental shelf into the bay and subsequently into the smaller associated embayments like New Bedford Harbor. Sediments within the bay range from muds and silts in the deeper regions to sands, gravels, and boulders in shallower areas nearshore and near the eastern head of the bay (Fig. 2.5). Almost all of the deposited sediments have terrestrial origins rather than marine, indicative of deposition from runoff or glacial activity.

Silt is found in the deeper, central regions of the bay generally below the 12.2-m contour (Figs. 2.4 and 2.5), with fine sand along the nearshore depositional areas of the north shore but medium sand close to shore on the south side. Coarse sand is also associated with the sandy protuberances extending out off Penikese, Pasque, and shoal areas, as well as in the vicinity of rocky submarine exposures around New Bedford Harbor, Nasketucket Bay, and the northeast shoal areas of the upper bay. Areas of coarser sand are swept by stronger currents that remove finer sediments (Moore 1963).

These physical features produced by glacial transport and sorting of benthic sediment by tidal and wind-driven currents have created a textural and depositional environment that exerts a significant effect on the distribution and composition of today's benthic plant and animal assemblages. The communities inhabiting rocky versus sand/silt and clay bottoms are very different because organisms attach to a rock substrate and burrow into a fine-grained one. Most of Buzzards Bay consists of fine sand to silt-sized sediments, and in these areas, sediment characteristics, including grain size and sediment composition, are major determinants of the structure of bottom-dwelling communities. Larval stages of many benthic animals, particularly invertebrates and bivalves, require certain sediment conditions for successful settlement. Grain size is a limiting factor for young larvae that burrow into the bottom and become established. The result is that given the relative stability of the sedimentary environment of Buzzards Bay (Moore 1963), the geologic history of the region has played a central role in the distribution of today's animal and plant communities.

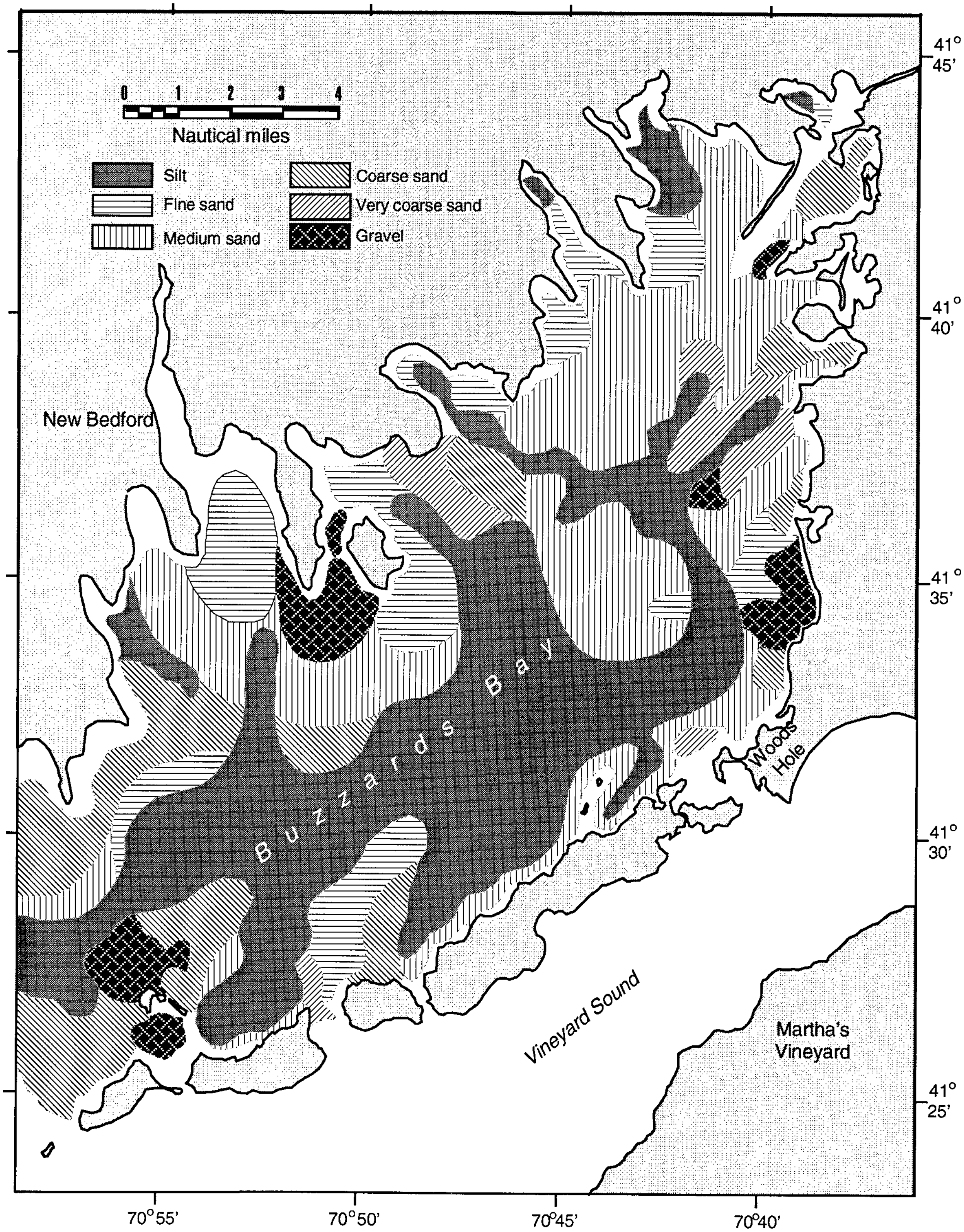
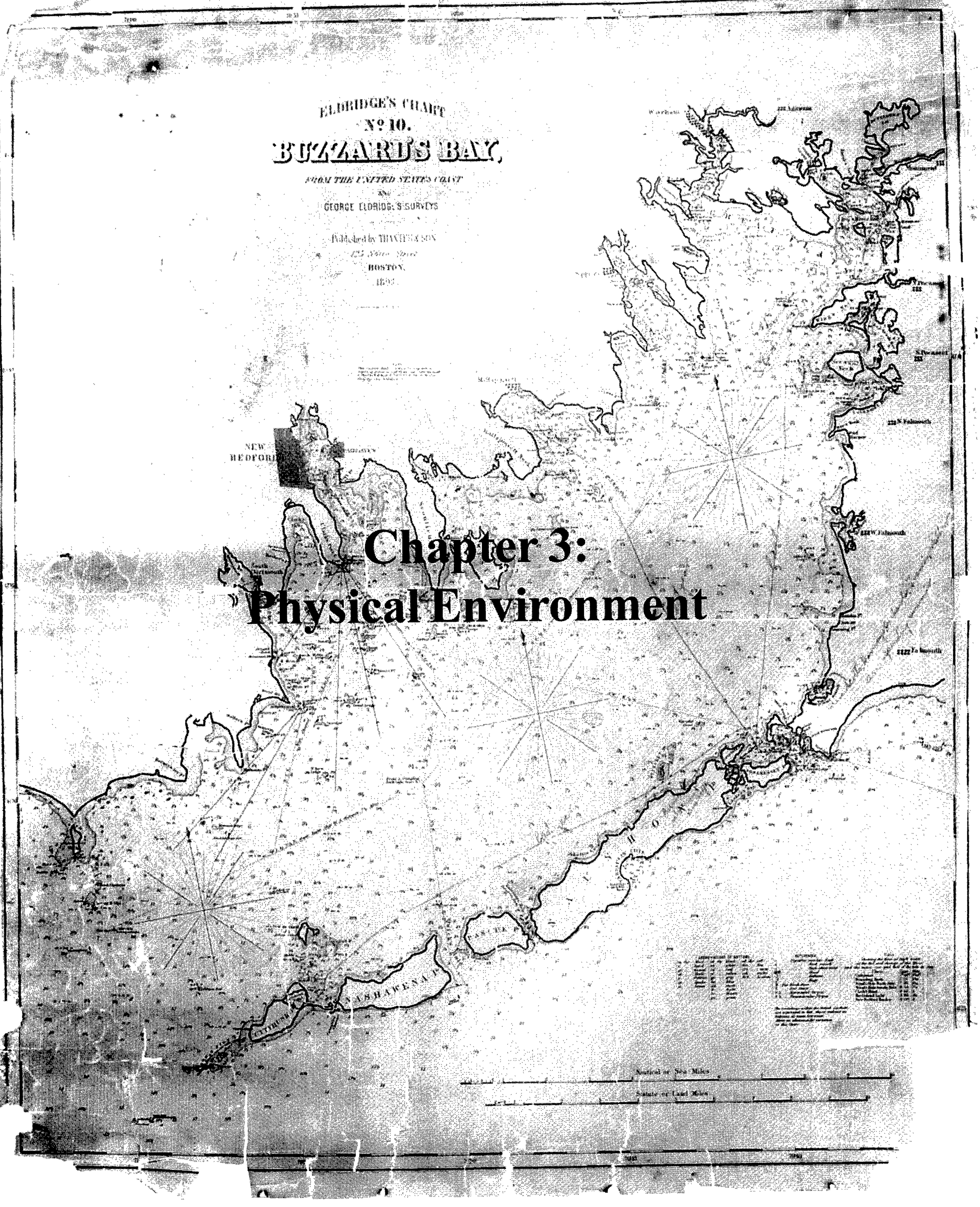


Fig. 2.5. Textural distribution of Buzzards Bay sediments. From Moore (1963).

Chapter 3: Physical Environment



3.1. Fresh Water: Rain, Surface, and Groundwater Flows

The watershed of Buzzards Bay is that region on which rainfall flows over the surface or through groundwater into the bay. In simplest terms, the fates of precipitation on the land surface are surface water runoff through rivers and streams, subsurface transport and discharges as groundwater, or return to the atmosphere via surface evaporation or uptake and loss by plants as evapotranspiration. The partitioning of flow between these various pathways has important consequences for nutrient and pollutant transport to and the salinity structure of bay waters. However, accurate partitioning for each embayment is complex and requires diverse long-term data sets and therefore has yet to be performed throughout this system. Measurements of groundwater discharges are also very limited and are confounded since many of the rivers and streams have significant groundwater contributions. However, rainfall has been measured over the long term at several locations around the watershed and limited river discharge data are available. Based on these data, it is possible to generate a general baywide picture of freshwater inputs. Given the highly permeable soils resulting from glacial outwash, significant amounts of fresh water reach the bay directly as groundwater discharge, and the rivers and streams around the bay have a significant baseflow (groundwater) component to their discharges. Glaciation has also affected discharge, as the western shore with its extensive outwash soils contains the major surface water flows to the bay, primarily along outwash channels. In contrast, the smaller watershed area and different deposits on the eastern shore yield an area dominated by smaller, generally groundwater-fed streams and direct groundwater discharges (Fig. 3.1, Table 3.1).

Precipitation is relatively uniform throughout the year with only a minor low during summer (Fig. 3.2A). However, this temporal uniformity in rain input does not translate into a constant freshwater input to Buzzards Bay. The temporal lag between

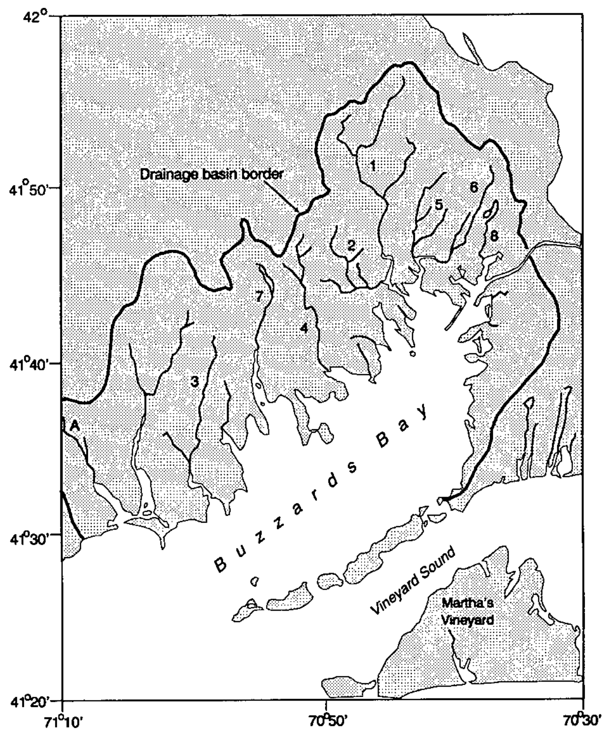


Fig. 3.1. Drainage basins and location of major streams emptying into Buzzards Bay. Westport River (A) has the only long-term stream gauge in the region. Numbers refer to rivers listed in Table 3.1. From Signell (1987).

Table 3.1. Estimated freshwater flows to Buzzards Bay. Numbers refer to locations of rivers on watershed map (Fig. 3.1). Adapted from Signell (1987).

Map symbol	River	Drainage area (km²)	Inferred basin flow (m³/s)	Contribution of flow (%)
A+A'	Westport (East+West)	216	4.3	19.6
1.	Weweantic	145	2.9	13.2
2.	Sippican	73	1.4	6.6
3.	Paskamenet	68	1.3	6.1
4.	Mattapoisett	62	1.2	5.6
5.	Wankinko	53	1.1	4.8
6.	Agawam	44	0.9	4.0
7.	Acushnet	43	0.8	3.8
8.	Red Brook	24	0.5	2.1
Groundwater + streams		377	7.5	34.2
Bay watershed total		1105	21.9	100.0

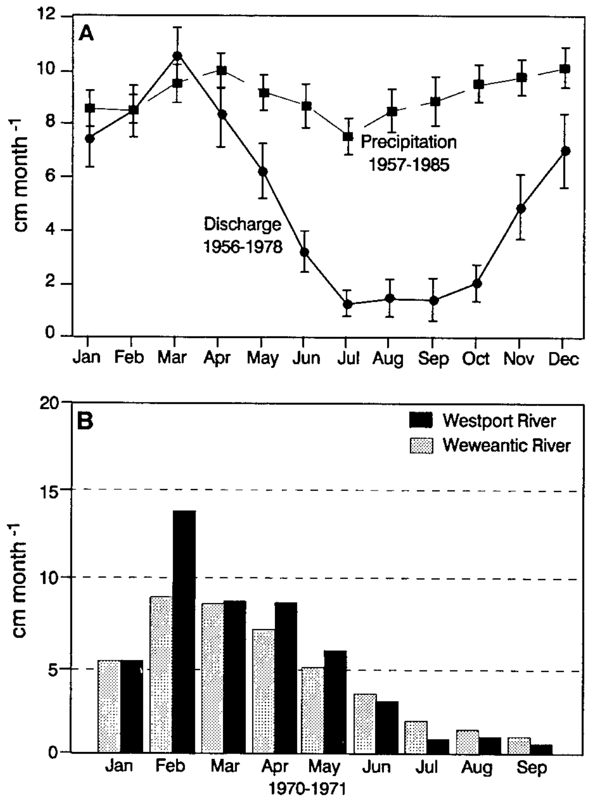


Fig. 3.2. A. Precipitation and mean monthly discharge of the Westport River, normalized by its drainage area. B. Comparison of normalized discharge from 2 years of data from the Westport and Weweantic Rivers. From Signell (1987).

inputs and discharges results primarily from strong seasonal shifts in recharge rates that are due to losses via evapotranspiration and to a lesser extent the storage of ice and snow during winter until spring melt. Annual return of rainwater within the watershed to the atmosphere is about 65% (45% recharge; LeBlanc et al. 1986). The integrated result of the cycles of precipitation, temperature, and evapotranspiration is a distinct seasonal variation in water table elevation with resulting variations in discharge.

Although river discharge data are limited, long-term measurements were conducted on the major river system, the Westport River (Fig. 3.2B), with smaller data sets available for the Weweantic River (cf. Signell 1987) and Red Brook (Moog 1987). The seasonality of river discharge is clear in the Westport and Weweantic rivers (Fig. 3.2B). Similar temporal variations caused by seasonal changes in hydraulic gradient were found in groundwater discharge into Buttermilk Bay (Weiskel 1991).

The similar discharge rates per unit of watershed for the Westport and Weweantic rivers over the same period (Fig. 3.2B) support the use of a generalized ratio of discharge/subwatershed area for each of the major rivers discharging to Buzzards Bay (Signell 1987). The ratio from the long-term Westport data is 0.0198 ($m^3/s)/km^2$, similar to a study by Bue (1970) for a nearby Cape Cod River of 0.0191 ($m^3/s)/km^2$. The bay-wide total freshwater inflow estimated from this approach is 22 m^3/s with the Westport and Weweantic rivers accounting for about one-third of the total flow (Table 3.1). While this technique does not separate the contribution of runoff versus groundwater inflow to total discharge, baseflow within this watershed is probably significant based on the geology and Red Brook, where approximately 69% of the total flow is baseflow (Moog 1987). Because of the relatively small watershed area versus bay area, the freshwater inflow (22 m^3/s) is nearly equivalent to the direct rain input to the bay surface (18 m^3/s), although evaporation of bay water must also be considered. Nonetheless, the importance of considering direct precipitation is clear. Although direct precipitation leads to dilution of bay salinities, it is less important than streamflow in producing salinity gradients within the bay waters.

The apparent temporal variation in freshwater discharge through surface and groundwater pathways and the nearly uniform monthly precipitation input directly to bay waters are consistent with the salinities observed in the open bay surface waters near the mouth. Salinity measurements collected over 14 years in Woods Hole, which receives a mean mass flux of water from Buzzards Bay and has almost no nearby freshwater discharges, indicate a small annual range of less than 1 ppt, with a minimum in April, maximum freshwater discharge in February-April (Fig. 3.2), and a maximum of 31.9 ppt in October at the end of the low discharge period (cf. Signell 1987).

3.2. Salinity, Temperature, and Density

The salinity of Buzzards Bay waters is the result of mixing of oceanic water with freshwater inflow (and rain). The distribution of freshwater input is consistent with the geology and watershed distribution and suggests that more than two-thirds of the inflow is along the western shore with the most concentrated flows near the head of the bay (Table 3.1, Fig. 3.1). The distribution of freshwater flow and the circulation pattern of the bay result in a gradient of decreasing salinity with increasing distance from the mouth of the bay (Fig. 3.3). The gradient is found in each season, but the greatest dilution is found in the April transect with surface waters at the head of the bay dipping to almost 28 ppt, consistent with the period of maximum freshwater discharge (Fig. 3.2A). The greater dilution of surface versus bottom water (Fig. 3.3) is typical of estuaries where the less dense fresh water enters near the surface over denser, cold saline bay waters.

As is the case for most of the New England coastal region, Buzzards Bay experiences great extremes in seawater temperature. Cape Cod is situated at the transition between the cold waters of the Gulf of Maine and the warmer waters of the Mid-Atlantic Bight; however, because exchanges are with Rhode Island and Vineyard sounds, they are primarily with warmer water lying south of Cape Cod. Buzzards Bay is included in the American Atlantic Temperate Region, which extends from Cape Cod south to Texas and is largely influenced by the warm waters of the Gulf Stream generated by the westward flow of the North Equatorial Current through the West Indies and Mexico and northward along the east coast of the United States. At Cape Cod, the current turns east and becomes the North Atlantic Drift, ultimately flowing to the British Isles and Europe. In contrast, Cape Cod and Massachusetts Bay are influenced by the Maine Current, a branch of the Labrador Current flowing south from Greenland. The temperature differences between Cape Cod Bay and Buzzards Bay can be as much as 5.5° C. Buzzards Bay water temperatures range over an annual cycle from 0 to 22° C in the bottom waters (Fig. 3.4) with greater extremes near the surface. The central bay typically remains ice free during the winter; however, occasionally the entire upper bay ices over.

Water column stratification occurs when less dense (warmer or fresher) surface water overlies more dense (colder or more saline) bottom waters. Periodic stratification occurs in Buzzards Bay (Fig. 3.3). The causes and level of stratification are not the same throughout the year. Vertical temperature gradients (Fig. 3.3), when they occur, are typically generated by radiative heating of the surface waters and are the dominant cause of stratification in the lower bay during summer (e.g., Fig. 3.3 top). Thermal stratification generally has a diurnal component and is readily broken down; however, because it occurs during the warmest months, its effects on dissolved oxygen balance below the thermocline may be generally more significant than the typical salinity stratification. Salinity stratification, while it can occur year-round in response to short-term meteorological events, is strongest in Buzzards Bay in spring when freshwater inflow is greatest (Fig. 3.3). Fortunately, spring water temperatures are low (Fig. 3.4), resulting in low oxygen demand and dissolved oxygen levels that remain high even during stratification.

For the most part water column stratification in the central region of Buzzards Bay periodically exists during summer months predominately because of thermal density differences but occasionally due to pulses of fresh water, causing salinity effects as well. Oxygen conditions in bottom waters of the central bay generally remain over 80% saturation (Howes and Taylor 1990; Howes 1993), and therefore the periodic stratification does not appear to significantly affect benthic communities. This condition is in strong contrast with the smaller embayments of the bay where freshwater inputs are most concentrated. Even in the shallow waters of the embayments, pulses of fresh water following summer storms add to thermal stratification, and short-term hypoxia can occur. Similar embayments (1-2 m deep) on the southern shore of Falmouth have

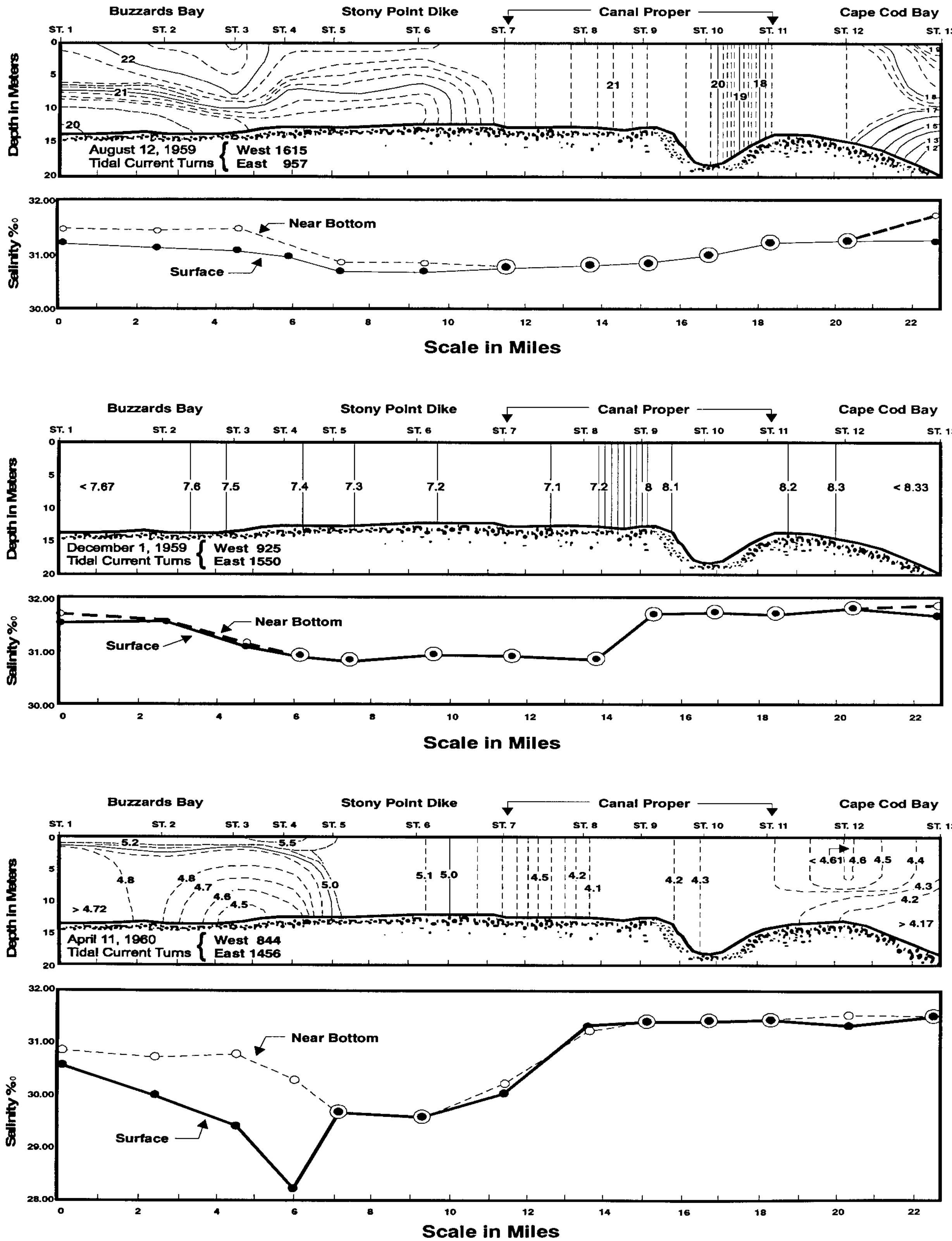


Fig. 3.3. Temperature and salinity profiles from the northern end of Buzzards Bay through the Cape Cod Canal and to Cape Cod Bay for (a) 12 August 1959; (b) 1 December 1959; and (c) 11 April 1960. Three distinct water masses exist: Cape Cod Bay water, "Cape Cod Canal water," and Buzzards Bay water. Transitional water within canal forms a boundary that fluctuates back and forth with each reversal of the tidal current. Anraku (1964a).

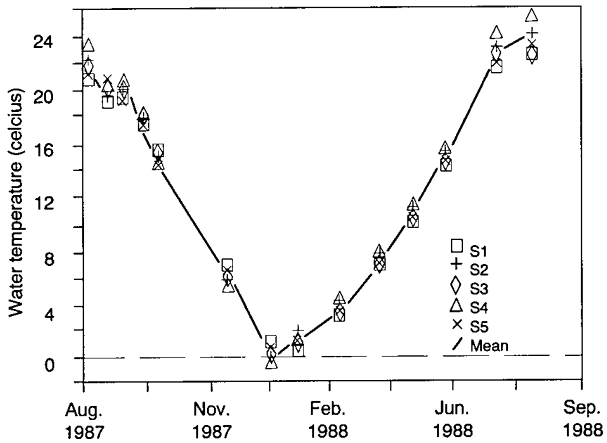


Fig. 3.4. Composite seasonal water column temperature in Buzzards Bay (Station 1) and New Bedford Outer Harbor (Stations 2-5). Data from Howes and Taylor (1990).

had water column anoxia and fish kills (from mid 1980's to present) related to periodic summer stratification (Costa et al. 1992; Howes and Goehringer 1992). For most of the year higher winds produce a well-mixed water column. It is unclear whether the low watershed-to-bay surface area ratio that results in the relatively low freshwater input also produces a lower frequency and/or weaker stratification of bay waters or if these processes in part maintain the stable benthic communities in the central basin of the bay. However, given the high oxygen demand of central basin sediments (Howes and Taylor 1989; Banta et al. 1990), prolonged stratification is likely to lead to low oxygen bottom waters. It appears then that the physical structure and the mixing processes of the Buzzards Bay system may be providing a potential buffer to biotic communities inhabiting the open bay.

3.3. Circulation/Currents and the Tidal and Wind Regime

Buzzards Bay is a relatively shallow estuary, with mean low water depths ranging from 5 to 10 m at the head to slightly over 20 m at the mouth. Depth profiles in transects across the bay show a relatively smooth asymmetric bottom near the head, gradually becoming more irregular and convoluted near the mouth. The circulation patterns within Buzzards Bay are predominately tidal and wind-driven flows acting on a large-scale estuarine density driven flow of about 1 cm/s (Signell 1987).

The location and semienclosed nature of Buzzards Bay result in tidal parameters significantly different from those found in the nearby waters of Vineyard Sound and Cape Cod Bay. To understand these differences, it is necessary to look at the New England Bight as a whole, from Long Island Sound to Buzzards Bay (Fig. 3.5). Tides in Buzzards Bay are predominately semidiurnal and dominated by the lunar cycle. The southern New England shelf tidal wave first reaches Rhode Island Sound in the "gap" between Block Island and Martha's Vineyard and then moves into the shallower basins of Vineyard Sound, Narragansett Bay, and Buzzards Bay. Due to the configuration of Buzzards Bay, the tidal signal is amplified by the shoaling and narrowing of the embayment toward the head, while the wave moving through Vineyard Sound is diminished due to interference with the progressing wave entering Vineyard Sound from the Gulf of Maine (Redfield 1953). The interaction of incident waves from the southern New England shelf and their reflection from the head of the bay dominate tidal parameters in Buzzards Bay.

The tide range is approximately 1 m with little or no temporal lag throughout the bay, the headwaters lagging only 20 min behind the mouth (Signell 1987). In contrast, Vineyard Sound operates more like a strait with tidal influence from two sources: the Gulf of Maine wave from the east and the southern New England shelf wave from the southwest. The effect is a decreased tidal amplitude and a significant temporal lag of roughly 2-4 h behind Buzzards Bay (Redfield 1953). The contrasting occurrence of the tidal wave within these two adjacent water bodies causes large phase and amplitude differences between the bay and sound and generates extremely swift currents between Buzzards Bay and Vineyard Sound (averaging 120-150 cm/s in Woods Hole and Robinsons Hole). These exchange

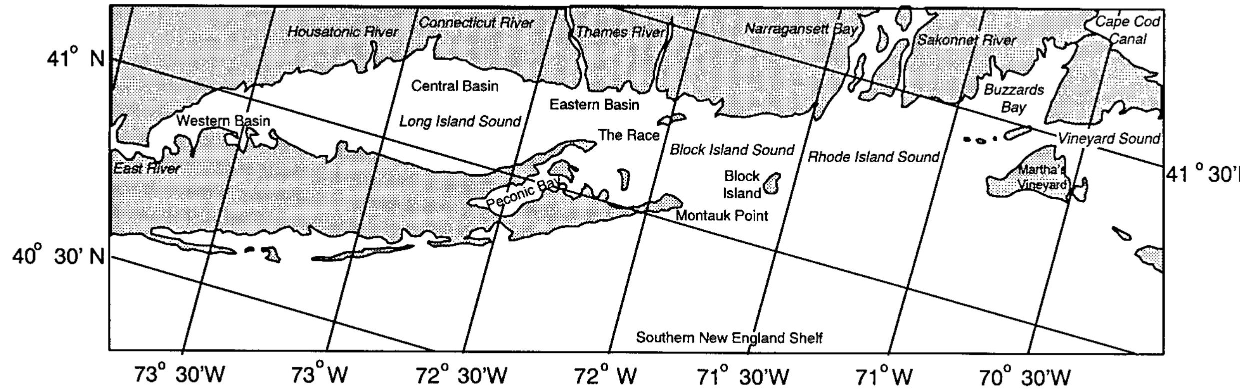


Fig 3.5. The southern New England Bight. From Spaulding and Gordon (1982).

current speeds are many times higher than the average speeds within the central (20-30 cm/s), head (<10 cm/s), or near the mouth (50 cm/s) of Buzzards Bay (Fig. 3.6). With less important consequences, differences in tidal phase and amplitude create strong currents through the Cape Cod Canal joining Buzzards Bay and Cape Cod Bay (Fig. 3.6). Mean tidal range in Cape Cod Bay is 2.8 m and averages 1.2 m in Buzzards Bay. The estimated turnover time of water within Buzzards Bay is about 10 days (Sumner et al. 1913; Moore 1963; Signell 1987).

Tidal current is the most important factor influencing sediment pattern, and two major currents within the bay proper predominate during ebb and flood tides. One current, running parallel to Naushon Island and terminating near Woods Hole, reaches 0.6 to 0.8 knots; the second is about 1 1/2 km wide and runs along the northwest shore of Buzzards Bay, with core velocities of about 0.6 knots. Midbay surface currents are weak, generally less than 0.4 or 0.5 knots, with no defined directional flow (Fig. 3.6). Although currents running between the islands do not extend far into the bay, they are important to bottom sediments near the islands forming sand protuberances into the bay. The well-sorted sediments found along the shore north of Woods Hole result from strong currents in this area (Moore 1963). The distribution and sorting patterns of shallow water sands are directly related to tidal currents, with accumulation of silts in deeper waters the result of bathymetric entrapment and less dynamic current activity (Moore 1963). Wind is also identified as a major factor in sediment composition because wind-driven wave activity creates high-energy waves in shallow areas of the bay, eroding areas unprotected by headlands. This erosion is indicated by a general coarseness of sediments found in these areas and the presence of greater accumulations of fine sediments on the southwesterly than on the northwesterly margins of harbors and coves (Driscoll and Brandon 1973).

Although tidal forcing is the dominant factor in the circulation within Buzzards Bay, other parameters influence localized currents, especially in the more restricted area near the head and the more sheltered harbors and embayments ringing the bay. Of the meteorological factors, local wind conditions are the most significant; however, nonlocal winds and atmospheric pressure are also important. Winds in this region are generally northwesterly in winter and southwesterly in summer, with local sea breezes often augmenting the southwesterly influence during summer months (Fig. 3.7). Major storms, however, often blow from the north or northeast, roughly along the long axis of the bay. In addition, variations in nonlocal wind and atmospheric pressure can lead to a rise and fall of average bay level. The

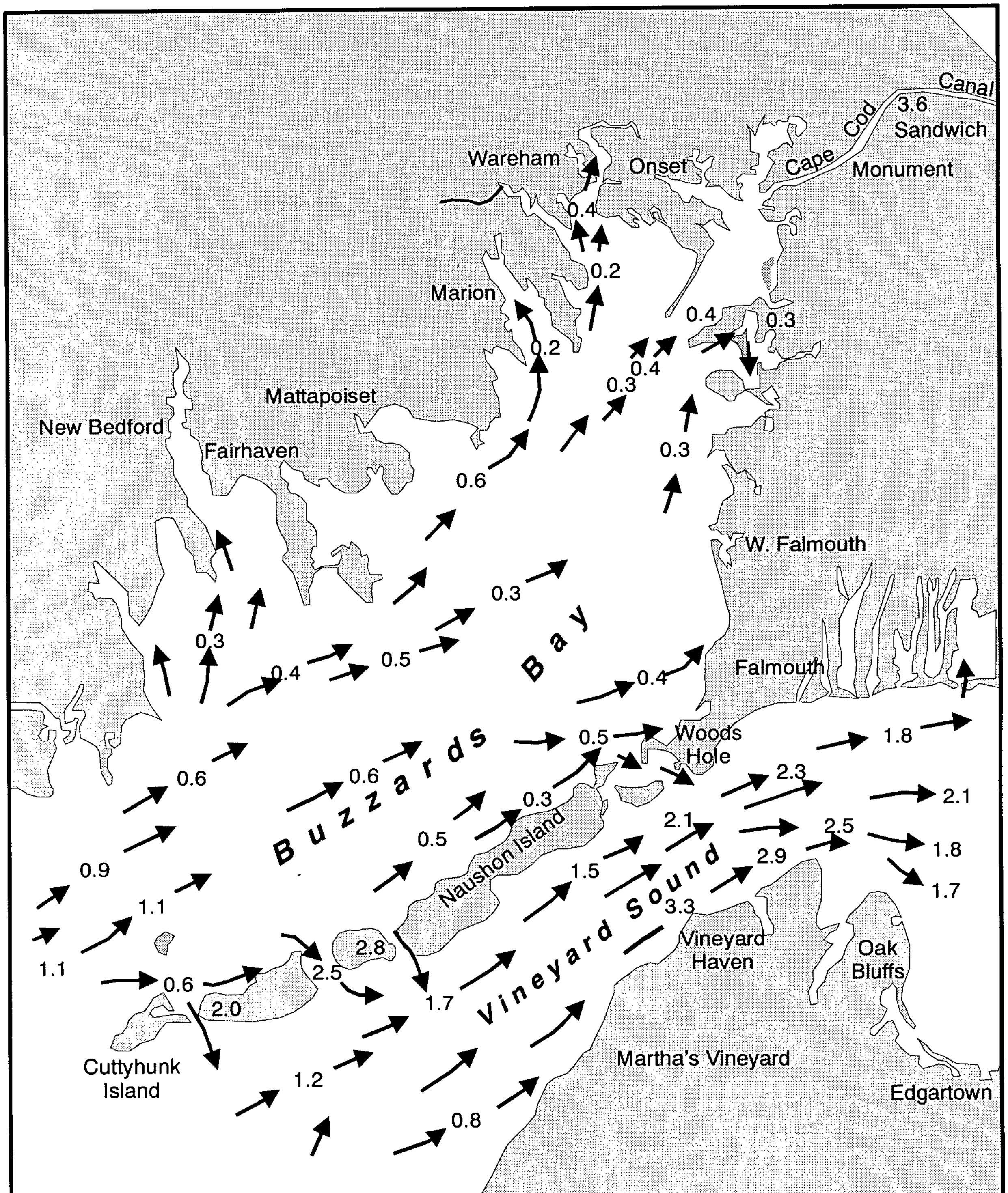


Fig. 3.6. Buzzards Bay tidal current chart showing flood currents 4 h after slack tide. Current speeds in knots. U.S. Department of Commerce, NOAA Tidal Current Chart. From Camp, Dresser, and McKee, Inc. (1990).

currents resulting from this "pumping," however, are relatively small compared with those created by local winds (Signell 1987). Winds along the axis of the bay are most significant in influencing circulation and are important to mixing, transport, and exchange for the bay (Fig. 3.7). Because of the more complex bathymetry at the mouth of the bay (Fig. 2.4), tidally induced "residual currents," or currents caused by the channeling of water as it moves across irregular surfaces, are of greater importance to subtidal circulation. Tidally induced eddies formed near the mouth of the bay (Signell 1987) can affect the fate of transported material.

The effects of local winds on circulation are most pronounced in the smaller, shallower fringing harbors and embayments. The circulation of New Bedford Outer Harbor, for example, is controlled by its enclosed nature. Although a weak pattern of "out on top, in on bottom" exists, it can be dominated by wind patterns such as a light southerly wind, which may stall surface movement (Camp, Dresser, and McKee, Inc. 1990). At its boundary with Buzzards Bay, circulation in New Bedford Harbor is more tidally driven. Flushing of New Bedford Harbor and many of the other harbors and smaller embayments results from a combination of tidal influences, winds, runoff, and warming of the shallower waters and can be variable depending on the dominance of any one or more of these parameters. Probably more important than the effect of tidal and wind-driven flows on water exchange is their effect on vertical mixing. Although stratification is generally weak the tidal currents near the head of the bay are also small. It appears that wind-driven mixing plays a major role in vertical mixing, hence affecting oxygen balance and biotic communities within this system.

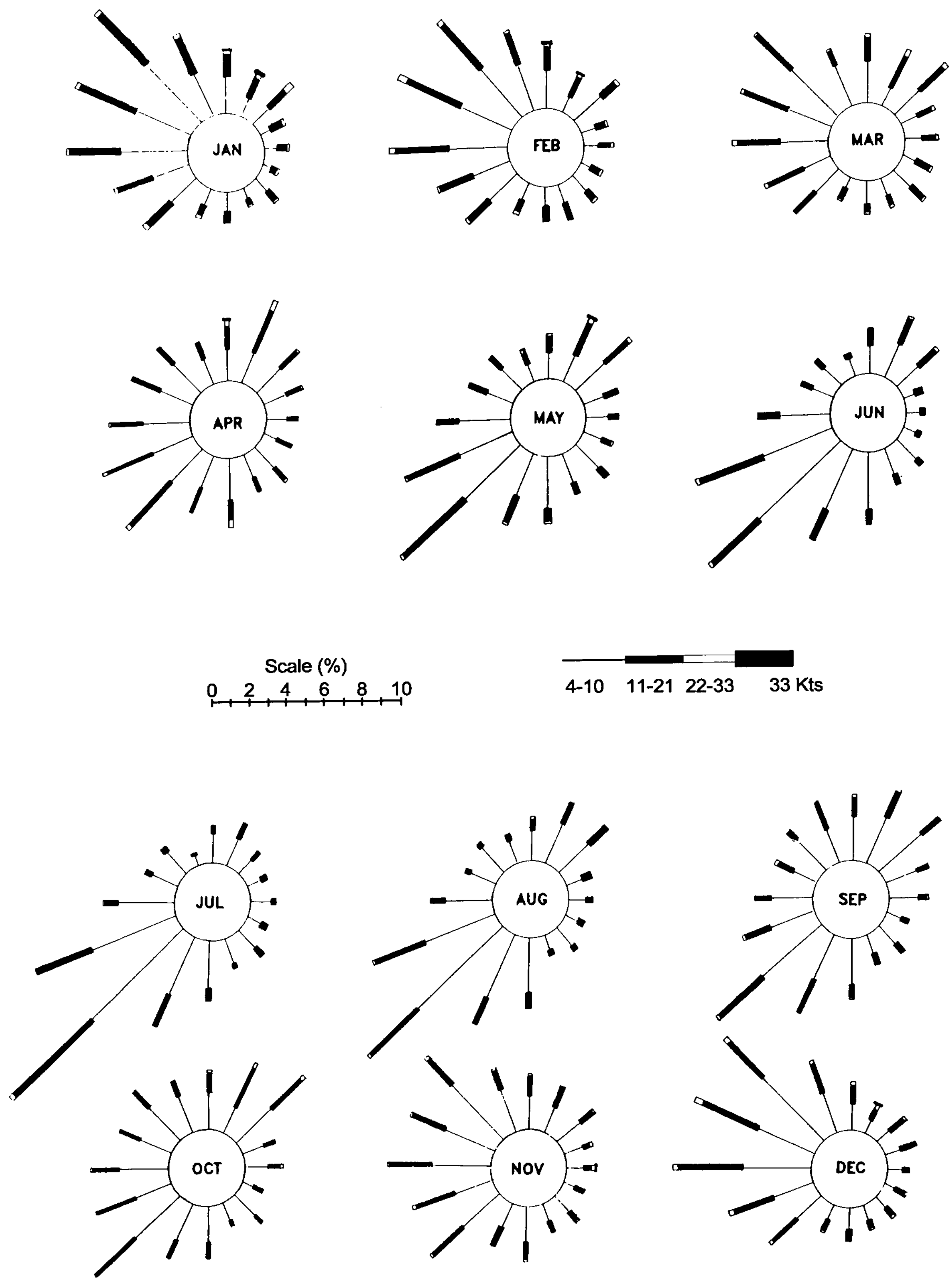


Fig. 3.7. Wind roses from 35 years of data at Otis Air Force Base, Bourne, Massachusetts. Wind direction is from north (upwards), with speed in knots. From Signell (1987).

Chapter 4:
Buzzards Bay Natural Resources

Buzzards Bay maintains a wide variety of habitats within its environs, representative of most ecosystem types found along the mid-Atlantic coast of the United States. Barrier beaches, tidal wetlands, tidal flats, rocky intertidal zones, and hard and soft sediment systems are found all along the perimeter of the bay, as well as circulation-restricted coves and embayments providing protected habitat for many plant and animal species.

The somewhat unique positioning of Cape Cod along the Atlantic coast has made it a zoogeographic barrier making Buzzards Bay the northern limit for many marine species. North of Cape Cod to Labrador (the American Atlantic Boreal Region), the biota is more arctic in species composition compared with the more temperate species found from the south of Cape Cod to Texas (the American Atlantic Temperate Region). Cape Hatteras forms another boundary to the south, and the region between Cape Cod and Cape Hatteras is known as the Virginian Province. Because of the influence of different currents (the Labrador and Maine currents from the north and the Gulf Stream from the south), water temperatures vary greatly between Cape Cod Bay and Buzzards Bay, with many cold water species ranging only as far south as Cape Cod, and vice versa. The mixing of Cape Cod Bay water with that of Buzzards Bay since the construction of the Cape Cod Canal has stimulated interest regarding potential changes in distribution of various species as a result of this physical alteration.

The shallow water areas within Buzzards Bay are strongly influenced by meteorological conditions and watershed inputs. Because they are shallow and generally have limited tidal exchange, these areas tend to have greater ranges of environmental conditions than those in the central bay. For example, embayment waters frequently warm more rapidly than the bay with approaching summer months and cool more rapidly with the onset of winter. In addition, as these nearshore waters are the immediate recipient of freshwater inputs from terrestrial sources, their salinity structure is more typical of estuaries. Another ecological stress in these embayments is ice rafting, which results from tidal fluctuations during winter months. Ice rafting often leads to the scouring of many shallow water areas including tidal wetlands and flats. This scouring often results in the disturbance of bottom-dwelling communities or the dislocation and movement of large sections of wetland peat. As a result of their structure, circulation, and proximity to nutrient inputs from the adjacent watershed, these shallow embayments tend to have higher rates of productivity than the central bay region on an areal basis and are more susceptible to periodic hypoxic or anoxic conditions in their bottom waters. The net result is a relatively environmentally stable central bay region, fringed with embayments presenting not only a variety of physical habitats but also a greater range in environmental conditions. In this chapter we describe the major habitats within the Buzzards Bay estuarine system and the dominant plant and animal species that help to define them.

4.1. Open Water and Embayments

4.1.1. Fauna

Benthic. The composition and distribution of benthic communities within Buzzards Bay are determined primarily by the sediment characteristics of the bay bottom (Table 4.1). Composition and grain size affect the ability of many benthic animals, notably invertebrates and bivalves, to settle and burrow. The benthic community that evolves is secondarily affected by the sediment organic content, which represents a carbon source for benthic deposit feeders and heterotrophic microbial communities. For a benthic community under a vertically well-mixed water column a high sediment organic content is beneficial. In areas where periodic stratification occurs, however, the concomitant high microbial respiration rates create low oxygen conditions in bottom waters, which can result in lower populations through reduced recruitment and larval survival or even shifts in benthic community structure towards lower diversity and more opportunistic species. It is the interaction between grain size

Table 4.1. Dominant soft-bottom, hard-bottom, and rocky intertidal communities in Buzzards Bay. Soft-bottom species listed comprise 95% of the species present by number. Hard-bottom species are listed when found to comprise more than 1% of the population. Data on soft- and hard-bottom species from Sanders (1958, 1960); rocky intertidal data from unpublished field surveys (Boston University Marine Program).

Substrate	Species	Class or phylum[a]
Soft bottom		
	Nuncula proxima	Bivalvia
	Nephthys incisa	Polychaeta
	Ninoe nigripes	Polychaeta
	Cylichna orzya	Gastropoda
	Callocardia morrhuana	Bivalvia
	Hutchinsoniella macracantha	Crustacea
	Lumbrineris tenuis	Polychaeta
	Turbonilla sp.	Gastropoda
	Spio filicornis	Polychaeta
	Retusa canaliculata	Gastropoda
	Stauronereis caecus	Polychaeta
Hard bottom		
	Ampelisca spinipes	Crustacea
	Byblis serrata	Crustacea
	Cerastoderma nulatum[b]	Bivalvia
	Ampelisca macrocephala	Crustacea
	Glycera americana	Polychaeta
	Nephthys bucera	Polychaeta
	Tellina tenera	Bivalvia
	Ninoe nigripes	Polychaeata
Hard bottom (cont'd)		
	Lumbrineris tenuis	Polychaeta
	Nepthys incisa	Polychaeta
	Molgula complanata	Tunicata
	Unciola irrorata	Crustacea
Rocky intertidal		
	Semibalanus balanoides	Crustacea
	Balanus balanus	Crustacea
	Carcinus maenas	Crustacea
	Cancer irroratus	Crustacea
	Pagurus longicarpus	Crustacea
	Littorina littorea	Gastropoda
	Littorina obtusata	Gastropoda
	Littorina saxatilis	Gastropoda
	Mytilus edulis	Bivalvia
	Modiolus modiolus	Bivalvia
	Crepidula fornicata	Gastropoda
	Nereis virens	Polychaeta
	Ascophyllum nodosum	Phaeophyta
	Fucus vesiculosus	Phaeophyta
	Chondrus crispus	Rhodophyta

[a]Phyla are listed for seaweeds, classes for other species.

[b]Because *Cerastoderma* populations are highly seasonal, it is not considered to be a good characterizing species for this community (Sanders 1958).

and organic matter and oxygen that appears to be structuring Buzzards Bay benthic communities today.

Sanders (1958, 1960) characterized the benthic communities in Buzzards Bay into two faunal groups or assemblages. The first is typified by deposit feeders generally present in softer, muddier sediments and dominated by the polychaete *Nephthys incisa* and the lamellibranch *Nuncula proxima.* The weak currents that allow organic matter to settle out in these areas provide a source of food for large numbers of these deposit feeders (average *Nuncula* density 30-40,000/m^2). Data from Sanders (1958, 1960) also indicate that the distribution of deposit feeders is strongly correlated to the percentage of clay, with the smaller clay particles having more surface area to bind organic matter. The second community is primarily found offshore in sandy bottoms and is made up mainly of filter feeders dominated by amphipods (*Ampelisca* spp.). The primary determinant for distribution of filter feeders is not fully known, but their communities generally predominate in areas of well-sorted fine sands indicative of moderate, relatively constant currents that provide sufficient food via suspension in the water column.

Driscoll and Brandon (1973) further divided subtidal habitats within Buzzards Bay into four functional groups: shallow protected, nearshore, open bay, and offshore. The shallow protected, nearshore, and offshore areas are generally characterized as having fine-grained sediments (mean grain diameter of less than 0.18 mm), analogous to the *Nuncula proxima - Nephthys incisa* communities identified by Sanders (1958, 1960). These three habitats have distinctly different sediment characteristics and faunal assemblages than the open bay areas (mean grain

diameter greater than 0.18 mm), more comparable to the *Ampelisca* assemblage (Sanders 1958, 1960).

The similarities in sediment type between the shallow protected and offshore sites are identified as the result of two sets of physical conditions. In the shallow protected areas, eelgrass, which is often prevalent, exerts a dampening effect on currents, resulting in deposits of fine-grained, silt- and clay-rich sand. Near the mouths of harbors sediments are generally fine-grained but poorly sorted, due to stream inputs carrying little or no coarse detritus and to deposition in a dynamic flow field with variable wind and wave activity. The sediments in the deeper offshore areas also experience less wave energy and lower current velocities and are afforded some protection by the dendritic troughs of the Pleistocene drainage system (Driscoll and Brandon 1973), resulting in the accumulation of fine-grained but less organically rich sediments. Offshore areas are generally characterized by water deeper than 9 m. The offshore molluscan macrofauna of northwestern Buzzards Bay is predominately represented by two species (making up 90% of all collected), *Nassarius trivittatus* and *Yoldia limatula*. In contrast, the shallow, more protected areas are colonized by a variety of molluscan fauna, dominated by *Crepidula fornicata, Nuncula proxima, Crepidula plana, Bittium alternatum,* and *Laevicardium mortoni*. The most obvious difference in fauna is seen in the abundance of *Nuncula proxima* in shallow, protected areas and its near absence from other areas.

Nearshore sediments maintain greater relative abundance of *Macoma tenta* and *Eupleura caudata*, with few *Nuncula proxima* and relatively fewer *Nassarius trivittatus* than the offshore areas. Open-bay environments, on the other hand, are substantially different from the other three subsystem types. Benthic communities of the open bay are generally characterized by suspension feeders, carnivores, herbivores, or nonselective deposit feeders such as *Nassarius trivittatus*, *Chaetopleura apiculata,* and *Anachis avara*. Sanders (1958) suggested that the fauna of stable sand bottoms is probably inherently more diverse than that of mud bottoms, most likely because of the more stable (less stressful) environmental conditions at these sites.

Overall the deeper parts of Buzzards Bay have maintained a stable benthic community for several decades. Nearshore areas that have been organically enriched (possibly by sewage), such as those within New Bedford Harbor, are dominated by *Mediomastus ambiseta*; this species is an opportunistic colonizer of polluted sediments or those subject to disturbances that limit recruitment of most other benthic organisms. Monitoring of infaunal populations has been conducted at what is known as the 301(h) Site offshore from New Bedford Harbor (Howes and Taylor 1989), and populations have shown little change from what Sanders found in the late 1950's and early 1960's. It appears that benthic populations within the central bay remain relatively "pristine," even in the region of New Bedford, which contributes almost all of the sewage to Buzzards Bay waters and almost half of the total nitrogen load. Even in this region, the impact on benthic communities appears restricted to nearshore areas (Howes and Taylor 1989; Costa et al. 1992).

Although sediment characteristics are important to structuring the infaunal assemblages in Buzzards Bay, the reverse is also true. Bioturbation and sediment reworking by benthic infauna are significant in structuring the biogeochemistry of these sediments. In fact, Rhoads (1963) estimated that although one species, *Yoldia limatula*, a deposit-feeding pelecypod, represented less than 10% of the total bottom fauna, it was potentially capable of entirely reworking the sediments within its range of distribution in the bay (Fig. 4.1). More than half buried, this clam ingests sediment, extracting food and ejecting waste several centimeters into the water, which eventually settles into small mounds around the siphon. Typical of deposit feeders, this species acts to mix surface sedimentary layers, alters the characteristics of some of the particles through aggregation into fecal pellets, and potentially increases the oxidation state of the surface sediments through the presence of its burrow.

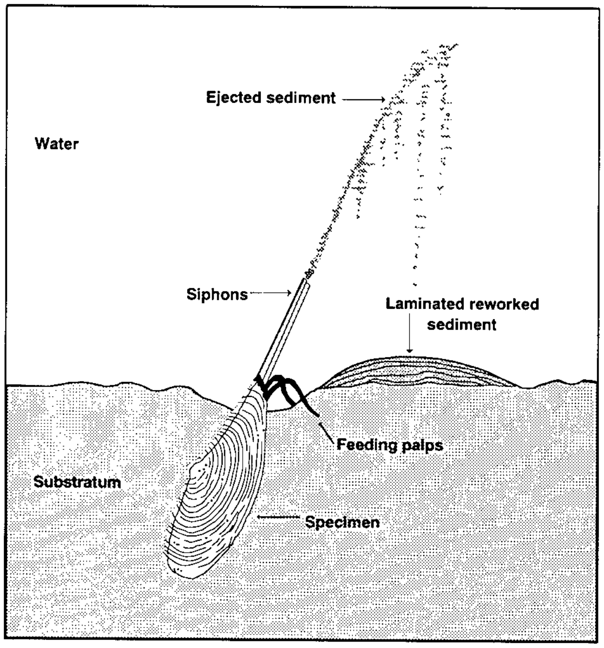


Fig. 4.1. Method of feeding and reworking of sediments by *Yoldia limatula*. From Rhoads (1963).

The state of oxidation or reduction of the benthic sediments at any one location is an integration of the type of benthic community, rate of bioturbation, and rate of delivery of organic-rich particles to the sediments. In areas with low organic matter delivery or deep burrowing, deposit-feeding communities the sediments are generally oxidized, and conversely more reducing (sulfitic) where high rates of organic deposition and shallow burrowing communities occur. In Buzzards Bay, physical disturbances can affect benthic communities and hence bioturbation by reducing the depth of bioturbation and increasing the sulfitic zone of the sediments; with sufficient time, the communities are reestablished. Over the past 100 years, however, nutrient and organic discharges to Buzzards Bay waters (e.g., New Bedford) have led to increased organic delivery to sediments in some areas, which appears to have resulted in the alteration of benthic communities. Whether the structuring factor is the rate of organic matter delivery directly or secondary effects of water column hypoxia or anoxia is unclear. The result is declining diversity and shallowing of the depth of bioturbation and therefore an increase in the sulfitic zone in those areas. This general scheme of alterations (Rhoads and Germano 1986) in benthic communities and sediment oxidation (Fig. 4.2) is occurring in Buzzards Bay today; the difficulty for ecologists and managers is to distinguish alterations driven by natural or physical forces from those driven by nutrients and organic matter.

Buzzards Bay sediments also play an important role in the life stages of many pelagic species. For instance, studies of the eggs of marine planktonic copepods in the bottom sediments of Buzzards Bay indicate that sediments may be part of an important pathway for recruitment of these organisms into the plankton community. The eggs, which have the ability to resist digestion when ingested by benthic predators, overwinter in the sediments and hatch in spring when water temperatures rise (Marcus 1984). In shallow coastal waters such as Buzzards Bay, storm events, current flow, and bioturbation also influence the transport and hatching of these eggs. Marcus (1984) and others (Dale 1976; Anderson et al. 1982) indicated this mechanism may also be important for dinoflagellate bloom formation, whereby large numbers of cysts and fine-grained sediment particles accumulate on the sea floor and are resuspended on a large scale by certain physical disturbances such as coastal storms. Marcus and Fuller (1989) later determined that physical mechanisms affecting sedimentation and transport can be used to predict the distribution and abundance of recently spawned eggs on the bay bottom.

Meiofauna. Meiofauna represent infauna from most marine phyla with the unifying trait that they are animals, mostly metazoans, that can pass through a 1.0-0.5 mm screen. Their role in organic matter cycling in coastal sediments is still an area of active research, but it is clear that they play a role in sediment microbial food chains and are consumed by deposit feeders. Meiofaunal populations in Buzzards Bay are overwhelmingly dominated by nematodes and kinorhynchs, composing between 89 and 99% of the total numbers (Wieser 1960). Certain species of nematodes appear to be restricted to particular sediment types; for instance *Odontophora* and *Leptonemella* species dominate sandy

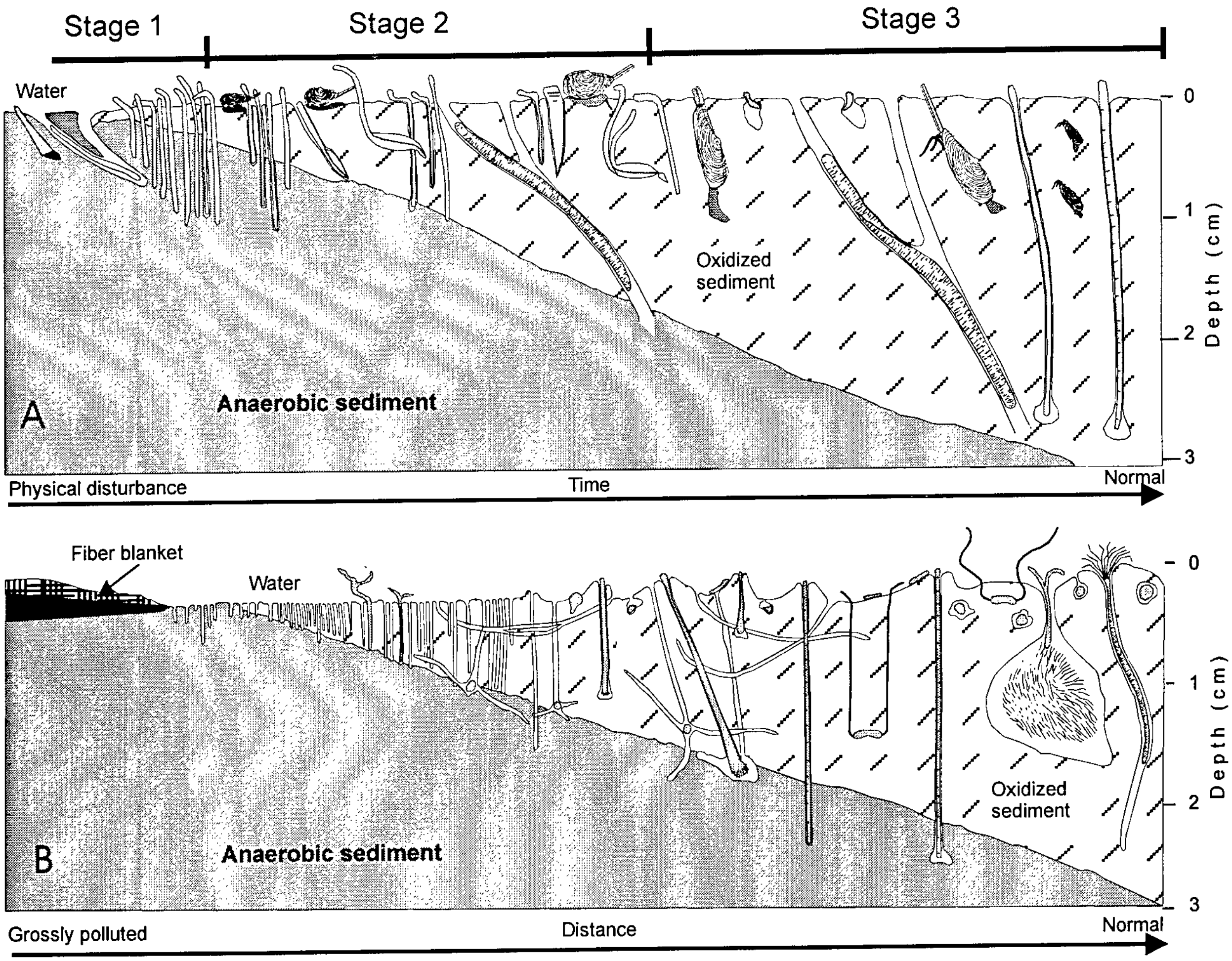


Fig. 4.2. Alterations in benthic communities and relation to sediment oxidation/reduction state under varying levels of (a) physical disturbance, or (b) nutrient and organic matter pollution. From Rhoads and Germano (1982).

sediments, whereas areas of finer grained, silty sediments are dominated by the nematode *Terschellingia* spp. and kinorhynchs such as *Trachydemus* spp. Observations of the distribution of these dominant metazoans are comparable to Sanders' (1958, 1960) sand and silt distinctions for macrofauna, with combinations of species determined by the relative amounts of sand versus fine deposits present.

Shellfish. Shellfish are benthic animals and in most cases infauna; however, because they support commercial and recreational fisheries, they have special conditions regulating their population densities. Shellfish are relatively fast growing and easy to harvest. Buzzards Bay, with its many protected harbors and embayments, provides numerous suitable habitats for hard-and soft-shelled clams, oysters, and scallops. Shellfish are also important in coastal food chains with large numbers of eggs and larvae entering the plankton during spring and summer months providing a food source for juvenile fish and crustaceans. Suitable habitat is important to the production of shellfish in that the young of various species require specific types of substrates or sediment grain sizes upon which to settle or burrow. Various shellfish species have specific salinity and temperature ranges for reproduction and growth. Water circulation also plays a role in maintaining temperature and oxygen conditions as well as in transporting planktonic food, since all of the harvested bivalve species are filter feeders. Hard-shell clams or quahogs, soft-shell clams, scallops,

and oysters are the dominant shellfish species in the bay, followed to a lesser extent by the edible blue mussel, which although easily gathered and delicious has not reached the popularity it has in Europe.

The most widespread shellfishery in Buzzards Bay is the hard-shelled clam or quahog, *Mercenaria mercenaria* (Fig. 4.3). Cape Cod is as the northern boundary to large-scale distribution of the species (Belding 1916), which is a warm water mollusk. Quahogs grow in shallow and deep water; however, they were primarily harvested in shallower waters until the advent in 1982 of a deep water dredge fishery in the bay. *Mercenaria* populate sandy to muddy sand bottoms generally in areas where salinity is above 15 ppt and can be found virtually along the perimeter of the bay. They burrow into the sediments and extend their siphons into the water column to feed. These clams are quite tolerant to short-period stresses such as bottom water anoxia; they can also survive during harvest when they are out of water for long periods by "clamming up," remaining with their shells closed until conditions improve. Larger individuals are extremely hardy and can survive days of anoxia or emerge from deep burial (tens of centimeters) caused by shifting sands or overwash during storms. Although these clams grow quickly and achieve marketable size in 3-4 years, they may live up to 25 years.

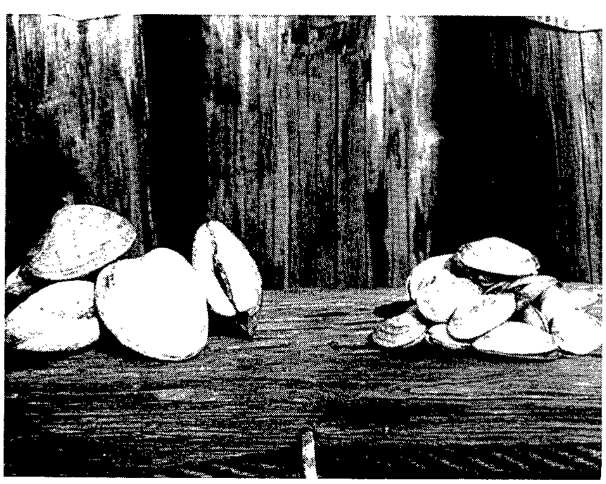


Fig. 4.3. Quahogs (*Mercenaria mercenaria*), left, and shoft-shelled clams (*Mya arenaria*), right. Photo by D. Goehringer.

Soft-shelled clams, *Mya arenaria* (Fig. 4.3), generally occur in sandy or muddy sediments in protected harbors and inlets and in salt marsh creeks, burrowed in the sediment with siphons extending into the water column. Their fragile shells are less tolerant to disturbance and are more easily broken than those of most other species of clams in the Buzzards Bay region. Because their shells do not close tightly (a portion of the siphon protrudes from the shell), they have limited tolerance to anoxia and can suffer high mortalities from sulfide accumulation under low oxygen conditions resulting from either natural or anthropogenic causes. Because these shellfish are more prevalent in soft, organic-rich sediments, occasional low oxygen conditions are likely due to oxygen depletion in bottom waters that results from microbial decomposition of this organic matter. Intolerant of salinities less than 5 ppt, they frequently inhabit low-energy embayments where organic matter can accumulate yet with sufficient flushing or limited freshwater inputs to maintain high enough salinity for reproduction and growth. The combination of low-energy, high organic matter environments and sensitivity to hypoxia can result in mass mortalities of this species, as have occurred in Cape Cod Bay (G.R. Hampson, Woods Hole Oceanographic Institution, personal communication). Because of the somewhat fragile nature of their shells, there has been recent interest in hydraulic dredging to decrease losses during harvest and increase yields over traditional hand-tonging.

In addition to infaunal bivalves, Buzzards Bay is recognized for its high productivity of the epibenthic bay scallop, *Aequipecten irradians* (Fig. 4.4; Gutsell 1930). Cape Cod is considered the northern limit for the scallop, which is less common in the colder waters to the north (Goode 1887; Davis 1989). The commercial scallop fishery in Buzzards Bay began in New Bedford in 1870, principally in the lower Acushnet River and Clarks Cove, and rapidly expanded to the upper regions of the bay (Davis 1989). Today, there are many areas around the bay where scallops still sustain an important commercial fishery, primarily in the Westport River but also in the Acushnet River and Clarks Cove on the western shore, West Falmouth and Wings Neck

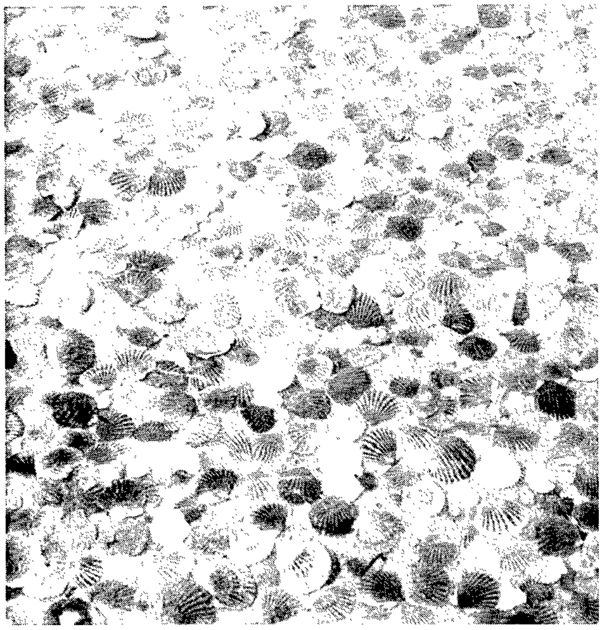


Fig. 4.4. Scallops *Aequipectin irradians*. Photo by D. Goehringer.

along the eastern shore, and the headwaters of the bay.

Adult bay scallops are highly mobile, propelling themselves through the water by expelling water through the rapid contraction of their shells by their adductor muscle. This muscle is highly prized for its delicate flavor and provides the main edible portion of the scallop. Bay scallops grow quickly and rarely live more than 2 years. Scallops have only one spawning season and environmental conditions can cause unpredictable sets (Lee 1980; Capuzzo et al. 1982). The combination of a short life span and limited spawning season is partially responsible for the large fluctuations in clean populations that drive the large annual variations in catch. Spawning generally occurs during early summer when water temperatures approach the annual maximum (20-24° C) and are coincident with phytoplankton blooms (Sastry 1966, 1968). Although bay scallops are generally most abundant in shallow embayments, they are also found, occasionally in large numbers, at depths of 4.5-12 m in Buzzards Bay (Capuzzo 1984). Studies of bay scallop gonads taken from offshore stations in Buzzards Bay (9 m depth) showed offshore populations spawned earlier and over longer periods than inshore populations (e.g., Wings Cove, 2-m depth). Although catches are less predictable in the offshore areas, the scallops appear to have 20-50% more muscle weight than specimens collected inshore (Capuzzo et al. 1982).

Scallops are filter feeders and as juveniles are sedentary, often attaching themselves by byssal threads to eelgrass (*Zostera marina*) blades above the sediment surface. The impacts of nutrient pollution—such as increasing epiphyte growth or turbidity in the water column, which decreases light availability—can have serious consequences for eelgrass beds, hence scallop populations, by eliminating an important substrate for the early growth of juveniles. Eelgrass blight or wasting disease, responsible for the loss of large expanses of eelgrass beds in various areas along the North Atlantic coast (1931-32), has indirectly been identified as the cause of subsequent declines in scallop populations in these regions. The presence of toxic pollutants such as heavy metals may also affect scallop populations. The scallop fishery in Acushnet River and Clarks Cove has declined in recent years, possibly as a result of exposure to the high levels of copper in New Bedford Inner Harbor and Outer Harbor sediments. Copper in the water column has been shown to reduce growth in these shellfish (Sindermann 1979; Davis 1989). Whatever the cause, scallop harvests have been low for the past decade.

Crassostrea virginica, the common oyster, is not as abundant in Buzzards Bay as other harvested bivalves. The entire eastern shore of the bay (Figs. 1.4, 3.1, and Table 3.1), the Agawam, Westport, and Weweantic rivers, Wings Cove, and parts of Sippican Harbor (in Marion) all support oyster beds. After going through initial juvenile stages, young oysters (known as "spat") require a hard substrate upon which to settle and grow and are often found on rocks, pilings, or frequently other oysters. As in the case of other bivalve mollusks, they are subject to a variety of natural predators (e.g., crabs, birds, sea stars, and oyster drills). Oyster harvesting is not presently a large commercial industry around Buzzards Bay, but evidence of past oyster harvests exists in shell middens, or shell

piles, left by the Native Americans in areas around the bay shores. In these shell middens, as today, quahogs were the dominant species, with fewer oysters and soft-shelled clams (Kitteridge 1930; Emery 1979).

Other species of edible shellfish are also found in Buzzards Bay waters but provide little recreational or commercial harvest. Black clams, *Arctica islandica*, similar in appearance to quahogs, can be found throughout the bay. Although they generally inhabit deep waters, they are also found in shallow regions. *Pitar morrhuanus* or the "duck clam" is also fairly common in soft bottom areas but is generally not harvested because of its strong flavor and weak shell. The common razor or Atlantic jacknife clam (*Ensis directus*) is abundant in the lower intertidal to subtidal sandy and muddy regions. As the clam burrows deeply, the sharp edge of its long slender shell can inflict a significant cut to the unaware barefoot clammer. Although it supports a recreational shellfishery, this clam's rapid escape into deep burrows limits the catch per unit effort in comparison to other species.

The only major crustacean harvested is the lobster (*Homarus americanus*). Lobstering represents an important commercial resource for Buzzards Bay and supports a small recreational fishery. Buzzards Bay is a spawning ground for lobsters. Larval lobsters hatch in Buzzards Bay beginning in late May, and the earliest larval stage is no longer found by mid-July (Collings et al. 1983). Significantly greater numbers of gravid females as a proportion of the total catch are typically observed in Buzzards Bay compared to regions north of Cape Cod. In 1987 the catch percentage of gravid females for Buzzards Bay was 31%, in strong contrast to the state average of 9.2%, and about double the 19% reported for the lobster fishery of the Outer Cape (Estrella and McKiernan 1988, 1989). The higher larval densities in Buzzards Bay compared to other Massachusetts and New England waters north of Cape Cod are likely due to warmer temperatures, resulting in the more rapid maturation of females and enhanced spawning stock levels (Lux et al. 1983). The bay's water residence time and warm spring to fall temperatures help to make it one of the more favorable areas for growth and spawning of lobsters in New England. In fact, Buzzards Bay "exports" significant numbers of larvae (10-20 million per year) through the Cape Cod Canal (Collings et al. 1983). The Buzzards Bay larvae and spawn from lobsters residing in the rocky bottom of the canal presumably help to support the lobster fishery in Cape Cod Bay.

Primarily nocturnally active invertebrates, lobsters generally hide during the daylight hours in rock or grass shelters, emerging during twilight hours to feed. Small lobsters frequent shallow waters near shore, while larger individuals (occasionally up to 22.7 kg) are more prevalent in deeper offshore waters. Relatively slow moving in their four-legged walk, lobsters have the ability to rapidly propel themselves backward for short distances by the contraction of their tails. The characteristic claws of the lobster perform two functions: the larger of the two, or "crusher," is designed for cracking hard objects like the shells of snails or bivalves; the smaller, sharper claw, or "cutter" is used for tearing apart prey (generally fish) or plant material. Lobsters are also known for their cannibalistic behavior, frequently eating other lobsters in their soft-shell (just past molting) stage and even their own young (Meinkoth 1981; Davis 1989).

Fish. Only limited quantitative data are available on the fish populations in Buzzards Bay because prohibition of net fishing in bay waters nearly a century ago eliminated catch records available from this source. There is, however, sufficient information to identify the prevalent species that make the bay home for part or all of their life cycles. The fisheries of Buzzards Bay are discussed in Chapter 5.

Reviews of the available data on Buzzards Bay fisheries identify 10 dominant fish species (excluding salt marsh fish described in a following section) currently found in bay waters (Table 4.2), with numerous other species occasionally present. As in other embayments, these include residents and nonresidents (migratory species), some commercially and recreationally valuable and others not. With its

Table 4.2. Dominant commercially valuable fish species in Buzzards Bay in order of post-1960 abundance and their food preferences (adapted from Davis 1989).

Common name	Scientific name	Food preference
Scup (or porgy)	*Stenotomus chrysops*	Assorted benthos, occasionally small fish
Butterfish	*Peprilus triacanthus*	Copepods, small fish, jellyfish, worms
Winter flounder	*Pleuronectes americanus*	Worms, gastropods, bivalves
Alewife	*Alosa pseudoharengus*	Copepods, shrimp, eggs, and larvae
Blueback herring	*Alosa aestivalis*	Copepods, shrimp, eggs, and larvae
Atlantic menhaden	*Brevoortia tyrannus*	Phytoplankton
Black sea bass	*Centropristis striata*	Mysids and other benthic organisms
Tautog	*Tautoga onitis*	Mollusks, crabs, worms, lobsters
Bluefish	*Pomatomus saltatrix*	Fish, worms, shrimp, lobster, squid, crab
Striped bass	*Morone saxatilis*	Fish, worms, shrimp, lobster, squid, crab

many coves, smaller embayments, salt marshes, and tidal flats, Buzzards Bay represents a significant spawning ground for southern New England, perhaps the best area in all of New England (Davis 1989). In conjunction with a larger spawning area, including Vineyard and Long Island sounds, large numbers of American shad (*Alosa sapidissima*), striped bass, and alewives *(Alosa pseudoharengus)* migrate into the bay's tributaries during spawning season, attracted by the shallow, warm waters and high productivity of the numerous smaller estuaries and rivers. These migrations have provided a seasonally dependable source of fish for centuries (Table 4.3). The following is a brief natural history of the commercially and recreationally important species dominant in the bay, with species information summarized from Clayton et al. (1978), Meinkoth (1981), Davis (1989), and other sources as identified.

Scup *(Stenotomus chrysops*). Also known as "porgy," scup are the most abundant fish in Buzzards Bay. The variable populations of scup are generally attributed to varying abundances of successive year classes with recruitment influenced by environmental factors rather than stock size. Summer and early fall residents of Buzzards Bay waters, scup migrate to deeper warmer waters in winter. Spawning migrations to inshore regions occur in late spring, with June the month of peak reproduction (Bigelow and Schroeder 1953). Scup eggs are buoyant, and studies in the Weweantic River estuary indicate eggs are most abundant from May through June in water temperatures of 8.5° to 23.7° C (Lebida 1969). Sudden temperature decreases occurring in late fall have been identified as a major environmental cause of scup mortality in bays and estuaries such as Buzzards Bay (Clayton et al. 1978). Their main predators are other fish such as cod, bluefish (*Pomatomus saltatrix*), and weakfish (*Cynoscion regalis*). Scup are primarily bottom feeders, consuming small crustaceans, worms, mollusks, squid, and occasionally small fish. The healthy benthic and bottom-living communities of Buzzards Bay appear to provide highly suitable habitat for this species, as reflected by its continuous occurrence from the earliest records to present.

Winter flounder *(Pleuronectes americanus*). Winter flounder was a mainstay of the New England groundfish industry until the mid 1930's;

Table 4.3. Dates of "first catch" for various species of finfish in Buzzards Bay recorded by a weir fishery for 1880. Data from D.W. Dean, as quoted in Goode (1887).

Date	Common name	Scientific name	Date	Common name	Scientific name
3/24	Atlantic menhaden	*Brevoortia tyrannus*	4/26	Rock bass	*Centropristis striata*
	Alewife	*Alosa pseudoharengus*	4/27	Sea robin	*Prionotus carolinus*
	Smelt	*Osmerus mordax*	4/28	Squid	*Loligo opalescens*
	Tomcod	*Microgadus tomcod*	5/8	Butterfish	*Peprilus triacanthus*
4/1	Tautog	*Tautoga onitis*		Kingfish	*Menticirrhus saxatilis*
	Skate	*Raja erinaceae*	5/11	Squeteague	*Cynoscion regalis*
	Perch	*Morone americana*	5/12	Flounder	*Paralichthys deutatus*
4/6	Sea herring	*Clupea harengus*	5/13	Bluefish	*Pomatomus saltatrix*
	Eel	*Anguilla rostrata*	6/7	Sand shark	*Carcharhinus plumbeus*
4/14	Shad	*Alosa sapidissima*	6/8	Stinging ray	*Dasuatis centroura*
4/15	Striped bass	*Morone saxatilis*	6/10	Shark (unknown species)	
4/17	Scup	*Stenotomus chrysops*	6/25	Bonito	*Sarda sarda*
4/24	Dogfish	*Squalus acanthias*	8/30	Spanish mackerel	*Scomberomorus maculatus*
	Mackerel	*Scomber scombrus*	9/6	Goose fish	*Lophius americanus*

however, after this time the populations suffered serious declines, the causes of which are as yet unclear. Winter flounders still support an important fishery in the bay, utilizing the coves and embayments for critical early stages of their life cycle. The spawning season for winter flounder is February in Woods Hole (Breder 1922) and February and March for the Weweantic River (Lebida 1969). Winter flounders are believed to return to the estuaries of their origin for spawning (Perlmutter 1939; Saila 1961), after which the nonbuoyant egg clusters remain on the bottom until hatching. Larvae are abundant from March through June in the bay waters (Lebida 1969; Fairbanks et al. 1971; Peterson 1975). The young winter flounders tend to remain within embayments during their first year, moving out into more open bay waters during summer months and returning to spawning areas late in fall. It is during the fall migration when the young of the species are most vulnerable to predation and fishing.

Winter flounders feed only during the day on a diet consisting primarily of polychaetes, bivalves, gastropods, and crustaceans. The winter flounder's habit of burrowing into sediments increases its potential exposure to many pollutants compared with midwater species and results in a higher incidence of fin rot and hepatic carcinomas in impacted areas such as New Bedford (Ursin 1972). Pollution, overfishing, and loss of important nursery grounds, particularly loss of wetlands, are all anthropogenic activities attributed as factors leading to the decline in this resource.

Alewife *(Alosa pseudoharengus)*. The rivers and tributaries of Buzzards Bay have historically sustained significant populations of alewives. These fish were a staple in the diets of early settlers and their abundance was synonymous with the relative prosperity of coastal towns (Clayton et al. 1978). The abundance and regularity with which the alewives returned each year resulted in dependence

on these fish, especially when other fisheries suffered decline. The value of the alewife fishery is evidenced by the substantial number of early laws and regulations in the statute books of the Commonwealth of Massachusetts protecting this resource. However, alewives and other anadromous fish around the bay have lost spawning habitat or access to historic spawning grounds because of obstruction of their inland migration. Alewife populations have declined sharply as a result. By 1913, the alewife fishery in Massachusetts had declined 75% from its original levels (Field 1913), and present levels are lower still.

In northern waters such as those of Buzzards Bay, alewives return to their spawning grounds as many as three to five times to spawn, whereas in southern regions they may spawn only once. Spawning migrations to freshwater ponds begin in late April to early May depending on water temperature. Alewife eggs are broadcast randomly at the spawning site, and larvae spend only their early stages in the freshwater pond, migrating out to the estuaries beginning as early as July and continuing through fall (Cooper 1961). Although they do not overwinter in the ponds, some do spend the rest of their first year in the estuary before migrating to the sea (Clayton et al. 1978). More recently, alewives have also been found to spawn in the brackish (up to 8 ppt) waters of coastal salt ponds, increasing their spawning habitat over that previously reported (Bourne 1983; Woods Hole Oceanographic Institution, personal communication).

Although historically caught by a variety of methods including gill nets, seines, and weirs, the largest numbers of alewives were caught in spring by nearshore weirs or by directly intercepting the fish on their way upriver to spawn. Capture was accomplished by stretching nets across rivers and simply scooping the fish into barrels. The most frequently identified rivers in Buzzards Bay for alewife migrations are the Acushnet, Wareham, Mattapoisett, Weweantic, and Agawam, referred to often in the historic literature for their seasonally prolific alewife catch. Alewives are still actively fished today, primarily by nets as they enter the spillways or streams to freshwater and coastal salt ponds.

Blueback herring (*Alosa aestivalis*). Often found with alewives (and commercially classified together with alewives as "river herring"), blueback herrings are anadromous fish and suffer similar declining populations resulting from obstructions to herring runs and the effects of pollutants on spawning stocks. These fish enter brackish waters to spawn in spring, usually by mid-May. Being more salinity tolerant, they have a reproductive advantage over alewives in that the population is not so dependent on the nursery potential of freshwater areas (Chittenden 1972; Clayton et al. 1978). Juvenile blueback herrings are common throughout Buzzards Bay in late summer and fall. This species feeds primarily on copepods, pelagic shrimp, fish eggs, and larvae. Herrings and alewives provide an important prey resource for many other species of fish, notably bluefish and striped bass.

Atlantic menhaden (*Brevoortia tyrannus*). Accounting for the largest portion of the United States catch, menhaden are primarily used for fish meal and oils rather than direct human consumption. Menhaden populations are often variable; no commercial landings were recorded from 1963 to 1968 in New England (Moss and Hoff 1989). The variable populations observed in Buzzards Bay may be due in part to their speed and schooling behavior, which make quantitative assessment difficult, especially since catches are generally from seines. They spawn at sea and in inshore waters, usually between April and October, and are typically most abundant in Buzzards Bay in late summer, when juveniles are prevalent. Juveniles and adults feed primarily in the upper water column on phytoplankton through filtration. Smaller crustaceans and various larvae are also consumed as the harvest of plankton is mainly size selective, similar to collection by towing a plankton net. The inshore distribution of menhaden is likely the result of the concentration of plankton in nutrient-rich coastal waters (Bigelow and Welsh 1924). Menhaden is considered an important prey species for most carnivorous marine fish, with a large population biomass seasonally concentrated in shallow waters.

Black sea bass (*Centropristis striata*). This fish is a summer visitor to Buzzards Bay, migrating

inshore in spring and offshore to deeper waters in late fall. The diet of adults consists of crustaceans, fish, and mollusks. Juvenile black sea bass utilize Buzzards Bay as a nursery ground and, as bottom feeders, eat primarily mysids in the shallow areas. Sea bass are born as females, transforming into males after their first spawning. As a result females tend to predominate due to their high percentage in young age classes. In contrast, recreational catch consists primarily of males, their larger size making them sought after by sport fishermen. The selective recreational catch may impact populations by altering sex ratios and decreasing the number of males available for reproduction (Davis 1989).

Tautog (*Tautoga onitis*). Tautog is an important sport fish; moving in from offshore waters in spring, this species is abundant in bay waters from May through September. As it does for most of the major species, the bay provides critical spawning and nursery habitat for tautog. Tautog spawning in Buzzards Bay is noted in historical records (Davis 1989) and the continued abundance of tautog is noted on species lists from 1620 to present. This species spawns in weedy, inshore areas, thus the many sub-embayments and coves, especially those with extensive eelgrass beds, are highly suitable for reproduction. The Weweantic River estuary is a frequent spawning ground for this species (Clayton et al. 1978). The buoyant eggs and juveniles remain inshore, with juveniles overwintering within the estuary, particularly in vegetated areas. The primary diet of tautogs consists of mollusks, blue and ribbed mussels, crabs, worms, and lobsters. The tautog population in Buzzards Bay may be slowly increasing based on the catch since 1980, which is primarily from recreational fishing and lobstering; however, no quantitative assessment exists at present.

Butterfish *(Peprilus triacanthus)*. Butterfish spawn during summer months in shallow waters throughout the mid-Atlantic Bight, and Buzzards Bay provides a nursery area for the species. Juvenile butterfish grow quickly and migrate offshore to deeper waters in late fall, returning again in April. The diet of the butterfish consists primarily of copepods, small fish, jellyfish, and polychaetes; in turn, butterfish are a prey source for bluefish, silver hake *(Merluccius bilinearis),* red hake *(Urophycis chuss),* and striped bass. It is an important commercial species all along the mid-Atlantic shelf and is frequently identified in the historic literature as being an abundant and important species for Buzzards Bay (Davis 1989). The schooling behavior and therefore patchy distribution of this fish results in variable year-to-year catch statistics. These variations are thought to be due primarily to limitations in catch rather than significant changes in the population (Davis 1989).

Bluefish *(Pomatomus saltatrix).* Seasonal migrations of bluefish represent an important recreational and commercial fishery during summer months in Buzzards Bay. Although spawning offshore, juveniles (known as "snapper blues") move in large numbers into the warmer inshore waters of the bay. These fish are voracious feeders, consuming a wide variety of fish and invertebrates in the water column. Mackerels, menhadens, alewives, herrings, and weakfish, as well as shrimp, lobsters, squid *(Loligo opalescens),* crabs, mysids, and annelid worms, are all part of the bluefish's diet. So efficient are they as predators, bluefish were frequently blamed for decreases in other fish species within Buzzards Bay waters (Baird 1873; Belding 1916). The abundance of juveniles in shallow nearshore waters also provides an important source of prey for other predaceous species. Large fluctuations in bluefish populations occur from year to year, but these fluctuations are attributed more to environmental factors than to human disturbances. The value of the recreational fishery, primarily surf-casting, party boat, and individual hook and line fishing, is estimated to exceed that for the commercial fishery for bluefish along the mid-Atlantic (Saila and Pratt 1973). Bluefish has been a consistently important food fishery for at least the past 100 years in Buzzards Bay. This species is also important in estuarine food chains; juveniles exploit prey in wetlands and embayments, and adults feed on the abundant larger prey species.

Striped bass *(Morone saxatilis).* Except when migrating, striped bass, another anadromous fish, is primarily a nearshore and brackish water species. The young remain in their natal estuary

until about 2 years old, with Chesapeake Bay being the primary spawning ground for most of the striped bass along the east coast. Striped bass are not known to spawn in Buzzards Bay waters; however, small fish (averaging 3-5 years old out of a potentially 20 year life span) are frequently found in the Weweantic River estuary, New Bedford Harbor/Acushnet River, and throughout the bay itself (Clayton et al. 1978). Although primarily a summer resident, some overwintering bass have been reported in southern Massachusetts rivers. Like bluefish they are voracious feeders, consuming fish and invertebrates such as herring, smelt, hake, squid, crabs, lobsters, and polychaetes. Striped bass represents one of the most important recreational species in the bay. Overfishing and natural annual fluctuations in populations have resulted in a recent 91-cm size limit for this species in Massachusetts.

Many species prevalent in Buzzards Bay depend on the brackish waters found in the many tidal wetlands bordering the bay for spawning areas and more often as nursery habitat and feeding areas. Many of the species discussed above are predatory, exploiting fish and animal populations in wetlands during early stages of growth. Shrimp and menhaden, although spawned at sea, often seek out these brackish waters for nursery grounds during their developmental stages, growing on the abundance of organic material provided in these systems. Tidal wetlands are temporary or permanent homes to many other species of fish as well. Mummichog *(Fundulus heteroclitus)*, striped killifish (*Fundulus majalis*), silversides (*Menidia menidia*), and four-spined sticklebacks (*Apeltes quadracus*) abound in Buzzards Bay salt marshes; other species, such as alewives, Atlantic menhaden, tautog, sea bass, winter flounder, and three-spined sticklebacks (*Gasterostrus aculeatus*), are only seasonal visitors, but their residence period in these marshes represents a very important stage in their life cycles. More information on these tidal marsh species is presented in the section on salt marshes.

Avian Fauna. The diversity of marine habitats within the Buzzards Bay system is reflected in the avian fauna. Marine and estuarine birds harvest the aquatic resources of the open bay waters as well as the bay's intertidal marshes and mudflats. More than 50 resident and migrant species rely upon bay waters for food and nesting habitat (Table 4.4), not including the various terrestrial species that opportunistically feed within intertidal areas.

Islands located around the bay (Ram, Bird, Gosnold, Nashauwena, Penekise, Pasque, and Cuttyhunk) are important nesting habitats for seabirds. For instance, as of 1984, Gosnold had over 1,000 nesting pairs of double-crested cormorants (*Phalacrocorax auritus*) in addition to a significant number of herring (*Larus argentatus*; 658 pair) and great black-backed (*Larus marinus*; 130 pair) gulls; Nashauwena supported nesting pairs of snowy egrets (*Egretta thula*; 30 pair), black-crowned night herons (*Nycticorax nycticorax*; 20 pair), common terns (*Sterna hirundo*; 140 pair), least terns (*Sterna antillarum*; 68 pair), roseate terns (*Sterna dougallii*; 2 pair), herring gulls (930 pair), and great black-backed gulls (200 pair) (B. Blodgett, Massachusetts Natural Heritage and Endangered Species Program, personal communication). Long-term studies of avian population dynamics are being conducted in this area by the Massachusetts Natural Heritage and Endangered Species Program and the Massachusetts Division of Fish and Wildlife. Of particular interest are Ram and Bird islands (owned by the Massachusetts Natural Heritage and Endangered Species Program), both of which are the subject of intensive bird recovery programs where attempts are being made to reestablish nesting colonies for roseate, least, and common terns. Increasing populations of nesting herring gulls and great black-backed gulls have diminished the availability of nesting sites for these terns. In addition, the gulls prey on tern eggs and young, increasing mortality. Attempts are being undertaken to increase tern nesting populations by discouraging or removing nesting gulls in formerly established tern sites, encouraging recolonization by the terns in these as well as new areas. Bird Island, a primary nesting site for the endangered roseate tern, is a prime example.

Table 4.4. Birds of Buzzards Bay.

Common name	Scientific name	Status[a]
Open Water		
Common loon	*Gavia immer*	C/W
Red-throated loon	*Gavia stellata*	U/W
Double-crested cormorant	*Phalacrocorax auritus*	N/C
Great cormorant	*Phalacrocorax carbo*	U/W
American black duck	*Anas rubripes*	N/C/W
Mallard	*Anas platyrhynchos*	N/C/W
Brant	*Branta bernicla*	C/W
Black scoter	*Melanitta nigra*	C/W
Surf scoter	*Melanitta perspicillata*	C/W
White-winged scoter	*Melanitta fusca*	C/W
Canada goose	*Branta canadensis*	N/C/W
Mute swan	*Cygnus olor*	N/C/W
Canvasback	*Aythya valisineria*	C/W
Greater scaup	*Aythya marila*	C/W
Common goldeneye	*Bucephala clangula*	C/W
Common eider	*Somateria mollissima*	C/W
King eider	*Somateria spectabilis*	U/W
Bufflehead	*Bucephala albeola*	C/W
American wigeon	*Anas americana*	C/W
Red-breasted merganser	*Mergus serrator*	C/W
Common black-headed gull	*Larus ridibundus*	C
Herring gull	*Larus argentatus*	N/C/W
Great black-backed gull	*Larus marinus*	N/C/W
Common tern	*Sterna hirundo*	N/C
Least tern	*Sterna antillarum*	N/U
Roseate tern	*Sterna dougallii*	N/U
Oldsquaw	*Clangula hyemalis*	C/W
Intertidal		
American oystercatcher	*Haematopus palliatus*	N/U
American (Great) egret	*Casmerodius albus*	N/C
Snowy egret	*Egretta thula*	N/C
Great blue heron	*Ardea herodias*	N/C/W
Striated heron	*Butorides striatus*	N/C
Black-crowned night heron	*Nycticorax nycticorax*	N/U
American bittern	*Botarus lentiginosus*	U
Northern harrier	*Circus cyaneus*	N/C/W
Osprey	*Pandion haliaetus*	N/C
American kestrel	*Falco sparverius*	C/W
Killdeer	*Charadrius vociferus*	U
Black-bellied plover	*Pluvialis squatarola*	N/C
Semipalmated plover	*Charadrius semipalmatus*	N/C
Piping plover	*Charadrius melodus*	N/U
Belted kingfisher	*Ceryle alcyon*	C
Willet	*Catoptrophorus semipalmatus*	N/C
Sanderling	*Calidris alba*	C
Spotted sandpiper	*Actitis macularia*	N/C
Semipalmated sandpiper	*Calidris pusilla*	C
Least sandpiper	*Calidris minutilla*	C
Dunlin	*Calidris alpina*	U
Sharp-tailed sparrow	*Ammodramus caudacutus*	N/U
Clapper rail	*Rallus longirostris*	N/U/W
Black rail	*Laterallus jamaicensis*	U
King rail	*Rallus elegans*	U

[a]N=nestor in Buzzards Bay; C=common, U=uncommon, W=winters in Buzzards Bay.

Sources: B. Blodgett, H. Hausmann, Massachusetts Division of Fisheries and Wildlife; Massachusetts Natural Heritage Program; Camp, Dresser and McKee (1990); Peterson (1980); Trull (1991); Massachusetts Audubon Society (1989); unpublished species lists. Many wintering birds are found year round.

A complete synthesis of the voluminous information on avian resources in the Buzzards Bay system is well beyond the scope of this text. In fact, entire texts could be, and indeed have been, devoted to the subject of birds on Cape Cod. Several worthy of note include Bailey (1968), Massachusetts Audubon Society (1989), and Trull (1991).

4.1.2. Flora and Aquatic Primary Productivity

The aquatic flora of Buzzards Bay reflects the diversity of physical environments discussed previously (Table 1.1). The water column supports phytoplankton communities having a range of productivity from the nutrient-enriched embayments with chlorophyll-*a* concentrations over 10 mg/m^3 to the open waters near the mouth of the bay at 1-2 mg/m^3 (Roman and Tenore 1978; Howes and Taylor 1991). Areas of the bay bottom above the photosynthetic compensation depth and intertidal flats support a variety of benthic floral types with diverse species assemblages. These floral types include macroalgae, particularly in the areas of hard substrate (e.g., rocky shores of the Elizabeth Islands) and in the shallow waters and intertidal areas; periphyton, which colonize the surface layers of sandy and muddy bottoms and intertidal flats; and subtidal (eelgrass) and intertidal (salt marsh) rooted macrophyte communities with associated periphytic and epiphytic associations (e.g., on eelgrass).

Because secondary production and habitat quality within Buzzards Bay depend directly on the amount and distribution of organic matter produced by phototrophs, it is useful to compare the relative amounts of organic matter produced by the different floral types. Although Buzzards Bay has been studied for more than a century, a quantitative baywide assessment of each of the floral assemblages is not available. However, enough data exist to make relative comparisons (Table 4.5).

Phytoplankton production has been determined in moderately detailed annual studies on the western (Symada 1990) and eastern (Roman and Tenore 1978) shores. It is likely that at least some of the three-fold higher carbon fixation along the western shore (360 g C m^{-2} year $^{-1}$) versus eastern shore (106 g C m^{-2} year $^{-1}$) results from the greater nutrient enrichment from loading in the New Bedford-Fairhaven area. Estimates of eelgrass and salt marsh production should be fairly accurate because of the availability of mapping studies (Hankin et al. 1985; Costa 1988a) and site-specific productivity estimates (Valiela and Teal 1979; Costa 1988b). Tidal export from salt marshes is also included in studies

Table 4.5. Annual primary production of the aquatic resources of Buzzards Bay (adapted from Costa 1988b).

Ecosystem component	Production (g C m^{-2} year^{-1})	Total: Area (ha)	Total: Production (t C/year)[a]	% of subtidal carbon cycle
Phytoplankton[b]	230	55,000	126,500	89.1
Benthic periphyton	45	2,076	930	0.7
Eelgrass - aboveground[c]	295	2,920	8,600	
Total	334		9,800	6.9
Eelgrass epiphytes	--	--	1,960	1.4
Macroalgae	500	400	2,000	1.4
Salt marshes - aboveground	160	1,993	3,200	
(Potential export)[d]			640	0.5
Subtidal Carbon cycle			141,830	100.0

[a]t = metric ton = 10^6 g.

[b]Area from Signell 1987. Production from: Camp, Dresser and McKee, Inc. 1990 (360 g C m^{-2} year^{-1}, Western Shore) and Roman and Tenore 1978 (106 g C m^{-2} year^{-1}, Eastern Shore).

[c]Area currently colonized as mapped by Costa 1988a.

[d]Area from Hankin et al. 1985. Production and export extrapolated from Great Sippewissett Marsh (Valiela and Teal 1979).

since the effects of salt marsh organic matter production on the open waters of the bay are based on detrital food chains. Periphyton, eelgrass epiphytes, and macroalgae are estimated from other systems and adjusted to approximate distribution within Buzzards Bay (Costa 1988a).

Although macrophytes have higher rates of production, Buzzards Bay supports essentially a phytoplankton-based (89%) carbon cycle. Although macrophyte production is more concentrated, phytoplankton photosynthesize throughout most of the water column of the bay and its embayments (Table 4.5). In addition, the areal extent of phytoplankton habitat is more than seven times that for all benthic floral types. Historically this distribution has not changed significantly given the relatively small contributions from wetlands and eelgrass beds. These latter plant communities, however, contribute more than organic matter. Eelgrass beds and tidal wetlands provide habitats with ecological processes and niches very different from those of the open bay. The concentration of organic matter production in these systems and the physical environment they create give them a disproportionate role in the secondary production of Buzzards Bay.

Phytoplankton and Zooplankton. Buzzards Bay phytoplankton populations are generally reported as being dominated by *Skeletonema costatum, Leptocylindrus minimus*, and species of *Rhizosolenia.* Zooplankton are dominated by the copepods *Acartia* spp. and *Paracalanus crassirostris.* Most of the phytoplankton productivity in Buzzards Bay is attributed to diatoms, with dominant species consisting of a mix of estuarine and coastal species commonly found in New England. Red tide blooms have not been significant in Buzzards Bay to date. Brown tides (Casper et al. 1987), so detrimental to filter-feeding communities and certain fish populations, have not been observed, although these phytoplankton have been reported in nearby Narragansett Bay.

Macroalgae. The distribution of macroalgae in Buzzards Bay appears to be controlled by temperature (lower bay waters are colder than those in the shallow embayments and upper bay), substrate, light, and nutrient availability. The temperature effect is particularly noticeable in the shallow regions, which exhibit distinct seasonal floras of winter and early spring versus midsummer and fall (Davis 1913).

Within the Buzzards Bay system there is a wide range of macroalgal habitats, each habitat containing a diversity of algal species. The shallow, high-light, nutrient-rich regions support the most luxurious growth. Brackish pools and intertidal areas within salt marshes have algal mats dominated by *Lyngbya* and *Microcoleus,* floating or loosely attached growths of *Enteromorpha* species, and patches of *Ascophyllum* along creek banks. The shallow embayments and nearshore zone of the open bay support green algae, *Cladophora,* with *C. flexuosa* and *C. arcta* abundant on hard substrates (rocks, piers) in spring and summer and *C. gracilis* forming dense accumulations in embayments in summer.

Those areas of rock or cobble shores (southeastern shore) support the most impressive macroalgal growth. The rockweeds, *Ascophyllum nodosum* and *Fucus vesiculosus,* abound on rocks in the littoral zone. Other hard-bottom (sand, shells, or rock) species of note are *Laminaria* spp., *Condrus crispus* and *Polysiphonia* (8 spp.) in deeper water and *Sargassum* and *Codium* in the shallower areas of the bay. *Phyllophora* is notable as being found at the lower depths on substrate ranging from rock to sand to mud and is distributed throughout the bay (Davis 1913).

Macroalgae are of concern to resource managers because dense accumulations can result from excessive nutrient loading to shallow coastal water bodies (Valiela et al. 1990; Costa et al. 1992). When they occur, these accumulations may have detrimental impacts on benthic communities, both infauna and fish. At the more modest levels of production generally found in Buzzards Bay, attached macroalgae can have the opposite effect, providing habitat for animals and increasing secondary productivity.

Eelgrass. Eelgrass, or *Zostera marina*, is a rooted subtidal macrophyte that forms extensive

beds in areas where light penetration is sufficient to support growth. Eelgrass is a perennial angiosperm (Fig. 4.5) that is able to flower and undergo pollination, seed dispersal, and growth completely underwater. Propagation of this species is primarily by rhizome within existing beds and by seedlings in new growth areas.

Eelgrass beds are important to the bay ecosystem as sources of organic matter production (Table 4.5), as habitat for invertebrate and fish species (Adams 1976; Thayer et al. 1984), and as a food source for geese (Buchsbaum and Valiela 1987). Eelgrass beds alter hydrodynamics and generate low-velocity zones, causing sediment and organic matter deposition that secondarily affect benthic animal communities. The roots and rhizomes serve both for nutrient uptake and binding the substrate. The plants themselves become a substrate for attachment of epiphytic organisms and the eggs and larvae of various species.

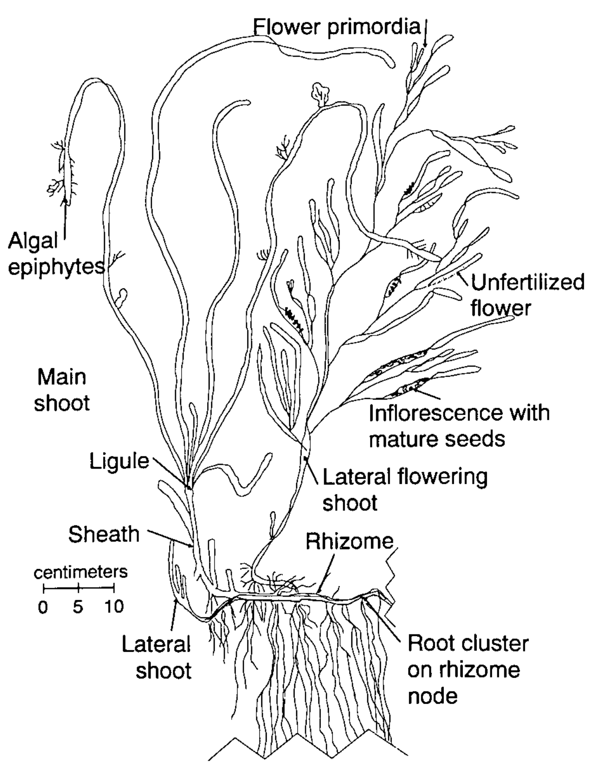


Fig. 4.5. The general morphology of the eelgrass *Zostera marina*. From Costa (1988a).

Buzzards Bay populations of *Zostera* appear to have generally recovered (Costa 1988b) from the catastrophic decline because of a "wasting" disease (Labarynthula), which decimated eelgrass beds throughout New England from 1931 to 1933 (Cottam 1933). Costa (1988b), using aerial photographs, determined that several years after the decline, eelgrass beds in Buzzards Bay covered less than 10% of the present area. Although epidemics of "wasting" disease have not reoccurred since the 1930's in Buzzards Bay, smaller outbreaks have been found in New England (Short et al. 1986).

Zostera appears to colonize sandy and mud bottoms of the open bay and its embayments. The major factor determining the upper limits of this subtidal species appears related to desiccation in summer and ice scour in winter (Davis 1913; Costa 1988b). While the lower limit is set by light penetration (Dennison and Alberte 1985, 1986), the level of light intensity is less important in determining depth than the daily duration of intensity above a physiologically set level.

Light penetration in simplest terms is a function of depth and the concentration of particles within the water column. The particles can be living (phytoplankton) or inert (sediments). Because Buzzards Bay has no large river discharging into it and relatively coarse-grained sediments resulting from its formation, the major source of particles attenuating light is generally phytoplankton within the water column (and epiphytes on the eelgrass leaves). As a result, light attenuation relative to eelgrass growth in Buzzards Bay may be more directly related to factors controlling phytoplankton and epiphyte density (e.g., nutrients) than in other systems with a higher inorganic load. Shallow protected embayments support less than one-third of the eelgrass of Buzzards Bay. The nearshore zone of the open bay, with its greater circulation and water transparency, contains beds as deep as 6 m, although 3-m beds are much more common. Compared to the open water areas, eelgrass growth in the more turbid embayments is restricted, generally growing in depths of 0.6 to 1.8 m (Costa 1988b).

Examination of the maximum depth of *Zostera* growth at sites throughout the bay (Fig. 4.6)

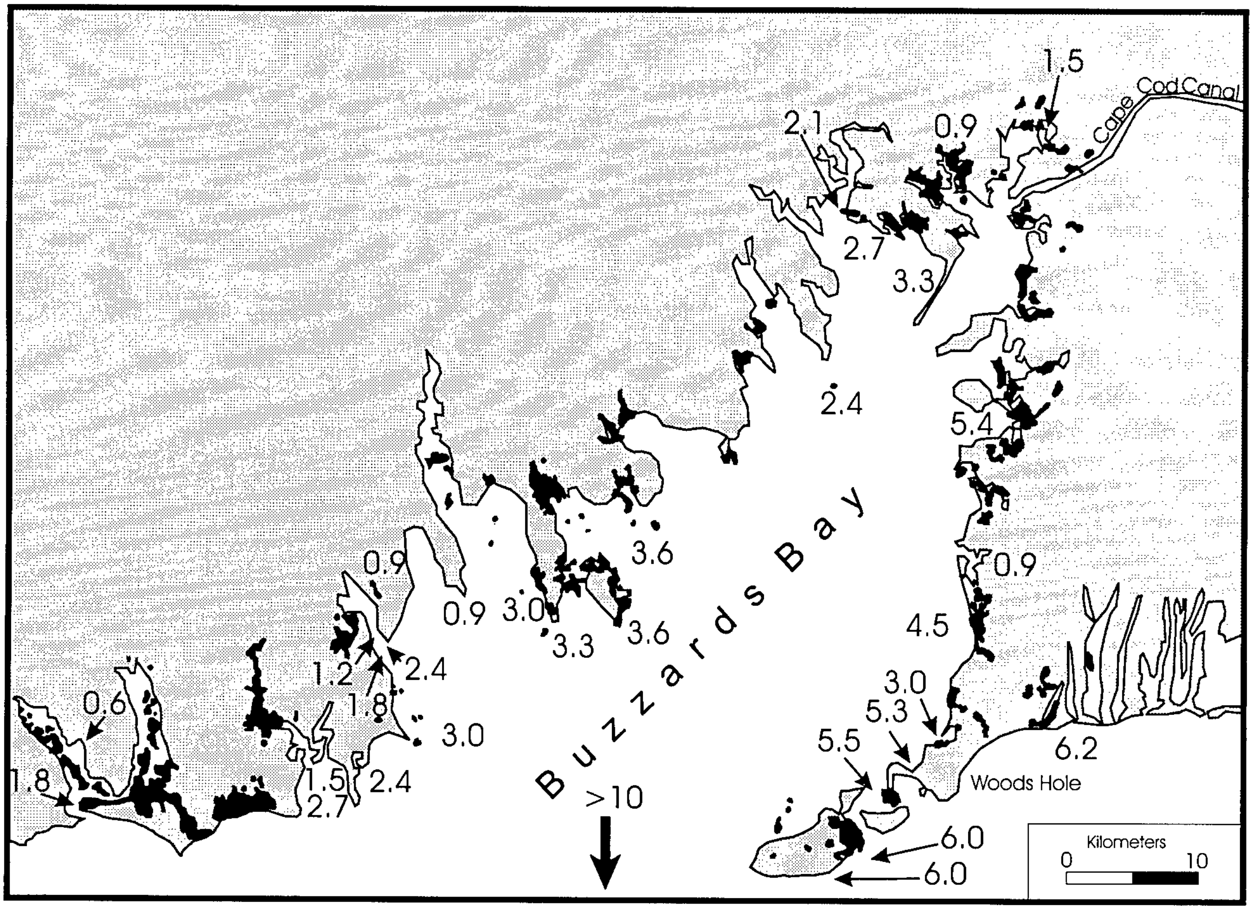


Fig. 4.6. Maximum depth (meters mean low water) of eelgrass (*Zostera marina*) in different parts of Buzzards Bay. From Costa (1988a)

Table 4.6. Eelgrass (*Zostera marina)* potential habitat area versus present area colonized in Buzzards Bay (adapted from Costa 1988a).

Town	**Habitat area[a] 0-3.6 m depth (ha)**	**Area of *Zostera* beds (ha)**	**Area of *Zostera* cover[b] (ha)**	**Habitat colonized by beds (%)**
Bourne	1,130	700	477	62
Dartmouth	823	151	104	18
Fairhaven	1,190	450	346	38
Falmouth	1,397	559	397	40
Marion	870	331	189	38
Mattapoisett	630	446	317	71
New Bedford	240	1	0.2	0.3
Wareham	1,480	914	564	62
Westport	1,420	389	265	27
Elizabeth Is.[c]	n.d.	540	270	–
Totals	>9,180	4,481	2,929.2	

[a]Almost all of current eelgrass beds are at or above 3.6 m depth (Costa 1988).
[b]Area of beds corrected for percent area colonized (% coverage).
[c]All values estimated, not directly measured.
n.d. = not determined.

suggests that the eastern shore, with its lower levels of nutrient loading and river flow, may have higher transparency and possibly better water quality than the western shore. This finding is consistent with the significantly lower levels of nutrients and phytoplankton productivity (Table 4.5) near Woods Hole where *Zostera* grows to 5.5 m versus the maximum depth in the New Bedford-Fairhaven area of 0.9 to 3.0 m. In general, however, the 3.6-m contour encloses almost all of the potential intensive growth area for *Zostera* in Buzzards Bay (Costa 1988 a,b).

Zostera covers extensive areas of the nearshore of Buzzards Bay and forms a nearly continuous band from Westport to Woods Hole. The area of existing beds is about 4,500 ha or about 8% of the subtidal area of the bay. Correcting the area of the beds for bare areas within the beds, the actual vegetated area is about 3000 ha (Table 4.6).

As in the case for the maximum depth of growth, the extent of theoretically habitable bottom actually colonized appears to be related to anthropogenic impacts. This is particularly clear in the case of New Bedford Outer Harbor, Dartmouth, and to a lesser extent Fairhaven, where only 0.3%, 18%, and 38%, respectively, of the available area has beds (Table 4.6), and much of the total terrestrially derived nutrient load enters the bay. The potential sensitivity of *Zostera* beds to nutrient loading (operating through phytoplankton and epiphyte effects) has served to make eelgrass a sentinel species for monitoring nutrient-related water quality of Buzzards Bay (Buzzards Bay Project 1990; Costa et al. 1992).

4.2. Intertidal

4.2.1. Salt Marshes

Salt marshes (Fig. 4.7) represent an important component in the ecology of Buzzards Bay (Tables 1.1 and 4.5). Salt marshes occur in pockets all around the border of the bay, including Little and Great Sippewissett in West Falmouth, Allen's Pond and Little River in Dartmouth, Weweantic in

Fig. 4.7. Aerial view of the Great Sippewissett Salt Marsh, West Falmouth, Massachusetts. Photo by B. Howes.

Wareham, along the Westport River, and Priest's Cove and West Island in Fairhaven. Westport has the largest area of salt marsh in the Buzzards Bay system, primarily due to the presence of the Westport River. In contrast, New Bedford has the smallest area, caused both by the physical structure of the harbor as well as by large-scale development that has occurred over the years. These tidal wetlands within the bay system are typical of New England marshes, generally forming behind protective barriers such as barrier beaches, or as narrow fringing marshes in low-energy environments such as circulation-restricted coves and embayments. The diminished velocities of tidal water as it enters these coves and embayments results in the deposition of suspended particles, ultimately resulting in the establishment of sediments at an elevation within the tidal range suitable for the colonization of marsh plants. The absence of high-energy waves is

important to the establishment of these species, as waves prevent the formation of a stable substrate (Redfield 1972). In the initial formation of a wetland, a gradation in sediment type exists, from sandy toward the mouth of the wetland to silty toward the head. This gradation reflects the characteristics of the suspended matter, as tidal waters have a lower ability to keep heavier materials like sand in suspension, resulting in sand deposition near the mouth and subsequent deposition of finer particles nearer the headwaters. Once the substrate is available at suitable elevation and the plants begin to colonize, the extensive root and rhizome systems of marsh species stabilize the sediments, and the marsh becomes established. About half of the production of the dominant low marsh species *Spartina alterniflora* is in belowground production.

The value of these highly productive intertidal wetlands has long been recognized—as habitat for waterfowl and shellfish, as storm buffers for adjacent upland, as nursery grounds for various species of fish, and as potential buffers for terrestrial nutrient inputs to coastal waters. Tidal flushing of salt marshes is also postulated as a mechanism for export of plant detritus to estuarine food webs in embayments like Buzzards Bay. Wilson et al. (1985) estimated between 5% and 7% of the organic matter in Buzzards Bay sediments was made up of vascular plant remains, with the bulk of the balance of organic matter derived from phytoplankton. They also estimated an export of $3\text{-}4 \times 10^5$ kg particulate organic carbon annually from marshes into the bay, amounting to 25-30% of the total amount of vascular plant debris in the top 1 cm of surface sediment.

Saltwater marshes in New England, including those in Buzzards Bay, are generally divided into two rather distinctive zones: the low marsh, dominated by the salt marsh cordgrass, *Spartina alterniflora;* and the high marsh, dominated by the salt marsh hay, *Spartina patens*, and the spike grass, *Distichlis spicata.* Flooding frequency and duration are the primary determinants to the distribution of low and high marsh zones. The low marsh zone is located between mean low water and mean high water, while the high marsh is the region lying between mean high water and spring high water. Both the low and high marshes are sufficiently flooded by seawater to inhibit the growth of more freshwater marsh plants such as *Typha* (cattail) and *Phragmites* (reed).

Low marsh is typically flooded on every high tide and is almost exclusively colonized by *Spartina alterniflora*, occasionally with *Limonium nashii* (sea lavender) or *Salicornia* (glassworts) present. *Spartina alterniflora* exhibits two growth forms, the tall form (up to 1-2 m in height), which grows 1-3 m inland from creeks, and the short form (less than 50 cm), which grows inland from the tall zone. The differences in these morphologies is generally attributed to a combination of nutrient availability, sediment oxidation, and plant-sediment interactions, with the more productive tall form growing in better drained, more oxidized sediments (therefore, plants possess increased ability to uptake nitrogen) with low concentrations of plant growth inhibitors (such as sulfides; Howes et al. 1986). In response to the anoxic sediments resulting from the high organic matter inputs and frequent inundation, these plants have adapted an aerenchyma system of gas-filled lacunae to transport oxygen to their roots and rhizomes, which support aerobic respiration and nutrient uptake (Teal and Kanwisher 1966; Howes and Teal 1994). The physiological difficulties of plant water uptake and evapotranspiration in saline sediments has been diminished by the evolution of salt glands, which secrete a concentrated salt solution to maintain osmotic balance while water is being lost during evapotranspiration. The naturally high levels of primary productivity found in salt marshes are generally attributed to the abundance of *Spartina alterniflora.*

The high marsh supports greater plant diversity than the low marsh and is dominated primarily by salt marsh hay and spike grass. Along the upland border where the duration of tidal flooding is least, salt-tolerant plants such as saltmeadow rush (*Juncus gerardii*), switch grass (*Panicum virgatum*), chairmaker's rush (*Scirpus americanus*), salt marsh bulrush (*Scirpus robustus*), and marsh elder (*Iva frutescens*) are commonly found. In most of the marshes around Buzzards Bay where the

headwaters are fresh or brackish, stands of reeds and cattails predominate at the landward edges of the wetlands. Although few animals live or burrow in the sediments of the high marsh zone, the historic utilization of salt hay as feed and fodder for animals and more recently its use as a weed-free garden mulch have focused attention on the value of these wetlands as a usable resource for almost four centuries.

Marine life is abundant in the salt marshes of Buzzards Bay, such as snails, crabs, mussels, amphipods, and large numbers of small fish. Many species of birds (wrens, rails, and wading birds; Fig. 4.8) feed on the fish and invertebrates, while others (Canada goose (*Branta canadensis*) and snow goose (*Chen caerulescens*); Teal 1986) feed on marsh plants. Mammals such as voles, field mice, raccoons (*Procyon lotor*), and skunks (*Mephitis mephitis*) forage in the marsh during low tides. Marshes are well known for their abundance of mosquitoes and biting flies, and great efforts are undertaken through management practices, such as ditching, to limit the habitat (primarily stagnant pools) required for breeding. Although considered a nuisance to humans and potentially carriers of diseases such as encephalitis, these insects provide substantial food for birds and surface-feeding fish in the wetland ecosystem. Other insects such as plant hoppers, grasshoppers, and aphids, as well as many species of amphipods and spiders, also are an important part of the fauna of Buzzards Bay salt marshes.

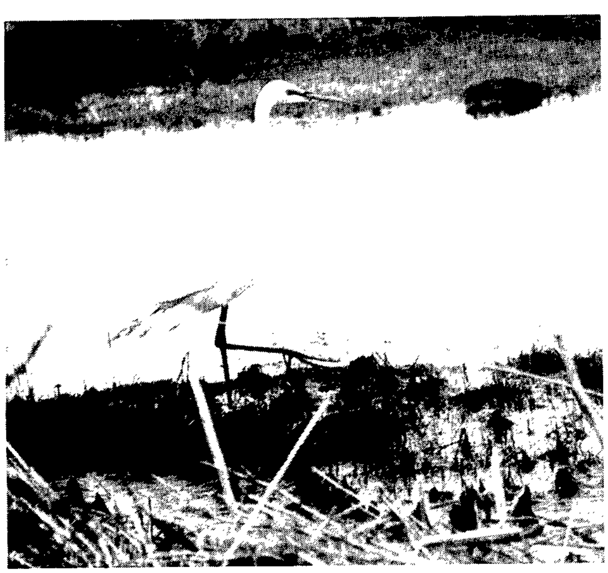


Fig. 4.8. The great egret (*Casmerodius albus*). Photo by B. Howes.

Molts of the horseshoe crab (*Limulus polyphemus*) and frequently the crab itself, are common sights around Buzzards Bay. Known as a "living fossil," horseshoe crabs have remained basically unchanged over the past 200 million years, with ancestors estimated to have roamed shorelines roughly 350 million years ago. Not actually a crab at all, *Limulus* is an arthropod, related to spiders and scorpions. The larger females move from deeper water in early summer to lay eggs along the high tide line. Horseshoe crabs are particularly interesting in that they possess a blue, copper-based blood with only one type of cell, which can be extracted for use in various medical assays such as identification of infections caused by spinal meningitis and *E. coli,* as well as certain types of cancers and blood clots.

Fish are an important part of the ecology of Buzzards Bay salt marshes, and as both predator and prey they represent an important component of the estuarine food web in the marsh-bay system. The tidal marshes of Buzzards Bay support resident species, which spend most of their life within the tidal creeks and pools of the marsh system, and nonresident or invading species, which enter into marsh waters and spend only a portion of their life there. Of the nonresident species, some are adults that enter into salt marshes to spawn, and others are juveniles of coastal species that use the marshes as nursery grounds.

The resident species of fish found in Buzzards Bay salt marshes are typified by the Atlantic silverside, the four-spined stickleback, and three species of killifish, mummichog, striped killifish, and sheepshead minnow (*Cyprinodon variegatus*). Spawning in the marsh, most of these fish are active from April through October and then move out of the marsh into deeper water or burrow into the bottom of tidal creeks or pools during winter. The

resident species are associated with the marsh throughout their life cycles. The most abundant of these, the Atlantic silverside (Fig. 4.9), lives only 1 year, and the relatively few that survive the winter by migrating into deeper waters return to spawn in spring. Mummichogs (Fig. 4.10) live several years, surviving the winter by residing in the bottom of creeks or marsh pools, often in the more brackish upper reaches of the marsh. The striped killifish on the other hand winters in the lower sandier reaches of the marsh during the winter months. These latter species utilize plants and animals in their diets, feeding on algae that lives on the surface of the marsh, but obtaining higher quality food through the consumption of eggs of other species like the horseshoe crab, small bivalves like *Gemma gemma,* and other invertebrates.

Fig. 4.9. The silversides (*Menidia menidia*). Photo by J. Teal.

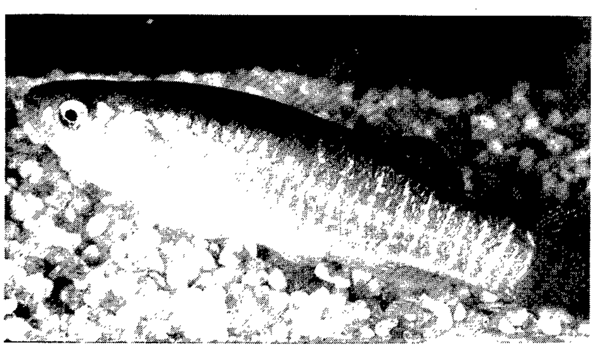


Fig. 4.10. The mummichog (*Fundulus heteroclitus*). Photo by J. Teal.

Nonresident species differ in their use of the marsh. Some use the marsh as spawning grounds, others for protective nursery grounds with abundant food for the growth of juveniles. The three-spined stickleback enters the marsh from Buzzards Bay in spring to spawn and then returns with its young back into the bay. Other invading fishes, such as the alewife, the Atlantic menhaden, the tautog, the sea bass, and the winter flounder use the marsh as a nursery ground and are only present as juveniles during mid and late summer. Bluefish and striped bass enter the marshes as moderate to large adults for brief periods during high tide and leave during ebbing tide, feeding on many of the smaller resident species in late summer.

In a study of the fish populations of Great Sippewissett salt marsh in West Falmouth, Werme (1981) found that resident fish were far more abundant than nonresidents (Table 4.7), as is often the case for other fish and bird assemblages. Two resident species, Atlantic silverside and mummichog, accounted for more than 90% of the fish in the marsh. Large differences were found in the growth rates between the resident and nonresident species, with nonresidents growing an average of 10 times as quickly as the resident fish (Table 4.8). Investigation of gut contents and fullness of the dominant resident and nonresident species were consistent with their different growth rates, with invading fish maintaining higher feeding rates than the resident fishes and generally consuming a higher percentage of animal foods (Table 4.9). Resident species tended to be more omnivorous, frequently with high levels of algae and detritus in their guts. While their diet was generally lower in quality than that of the nonresidents, resident species increased the percentage of animals in their diet during spawning and overall maintained much larger populations (Table 4.7).

Other nondominant species found in the marshes of Buzzards Bay include bay anchovy (*Anchoa mitchilli*), sheepshead minnow, American eel (*Anguilla rostrata*), striped mullet (*Mugil cephalus*), northern pipefish (*Syngnathus fuscus*), butterfish, black sea bass, cunner (*Tautogolabrus

Table 4.7. Occurrence and abundance of resident and nonresident salt marsh fishes. Percent occurrence (corrected for distance) for each of three areas, the main channel (M.C.) which connects to Buzzards Bay, sandy creeks and muddy creeks (the furthest landward). Averages are shown ± SE. Asterisk (*) indicates significance of t-test at 0.05 level of significance. (From Werme 1981).

Species	Seasonal occurrence	Abundance/ 100 m	Percent occurrence		
			M.C.	Sand	Mud
Residents					
Menidia menidia	Apr. - Oct	151.7 ± 84.4	32	56	12
Apeltes quadracus	Apr. - Oct.	0.2 ± 0.0	67	33	0
Fundulus heteroclitus	Apr. - Oct.	110.8 ± 12.8	11	42	47
Fundulus majalis	Apr. - Oct.	11.5 ± 5.0	16	82	2
Cyprinodon variegatus	Apr. - Oct.	9.9[a]	0	61	39
Average		56.8 ± 31.1	25 ± 14	55 ± 12	20 ± 7
Nonresidents					
Alosa pseudoharengus	July - Sept.	1.8 ± 0.0	58	32	9
Brevoortia tyrannus	Aug. - Sept.	1.3 ± 0.1	0	64	36
Gasterosteus aculeatus	Apr. - June	0.4	22	48	30
Tautoga onitis	June - Sept.	0.4 ± 0.2	77	23	0
Centropristes striata	Aug. - Sept.	0.5 ± 0.2	0	100	0
Pseudopleuronectes americanus	May - Sept.	0.5 ± 0.2	19	53	28
Average		0.8 ± 0.3	29 ± 12	53 ± 11	17 ± 7
t-test		*	NS	NS	NS

[a]Standard error not available.
NS - not significant.

Table 4.8. Mean total length and average percent increase in length/month of resident and nonresident salt marsh fishes. Averages are shown ± SE. Asterisks (**) indicate significance of t-test at 0.01 level of significance. (From Werme 1981.)

Species	Mean length	% length/ month	Species	Mean length	% length/ month
Residents			**Nonresidents**		
Menidia menidia	51 ± 0	30	*Alosa pseudoharengus*	62 ± 2	100
Apeltes quadracus	28 ± 0	10	*Brevoortia tyrannus*	78 ± 5	--
Fundulus heteroclitus	42 ± 2	20	*Gasterosteus aculeatus*	27 ± 1	400
Fundulus majalis	50 ± 0	20	*Tautoga onitis*	50 ± 0	180
Cyprinodon variegatus	35 ± 0	10	*Centropristes striata*	40 ± 5	100
			Pseudopleuronectes americanus	88 ± 24	--
Average	41.2 ± 4.4	18.0 ± 3.7	Average	57.5 ± 9.4	195.0 ± 70.9
t-test	NS	**	t-test	NS	**

NS - not significant.

Table 4.9. Average gut fullness, percent fish with empty guts, and percent carnivory, herbivory, and detritivory in the diets of resident and nonresident salt marsh fishes. Averages are shown ± SE. Asterisks (**) indicate significance of t-test at 0.01 level of significance. (From Werme 1981.)

Species	Average gut fullness	Percent empty guts	Carnivory	Percent Herbivory	Detritivory
Residents					
Menidia menidia	36.3 ± 1.0	34	70	20	10
Apeltes quadricus	32.8 ± 4.4	49	80	5	15
Fundulus heteroclitus	24.8 ± 0.9	51	23	52	25
Fundulus majalis	18.0 ± 0.9	53	55	15	25
Cyprinodon variegatus	18.0 ± 1.4	57	13	61	26
Average	26.0 ± 3.7	49 ± 4	48 ± 13	31 ± 11	20 ± 3
Nonresidents					
Alosa pseudoharengus	62.3 ± 4.7	18	97	0	3
Brevoortis tyrannus	52.5 ± 12.1	0	0	67	33
Gasterosteus aculeatus	56.8 ± 4.7	26	90	0	10
Tautoga onitis	78.5 ± 1.0	0	100	0	0
Centropristes striatus	40.0 ± 8.4	6	90	0	10
Pseudopleuronectes americanus	65.0 ± 6.9	0	90	0	10
Average	59.2 ± 5.3	8 ± 5	78 ± 16	11 ± 11	11 ± 4
t-test	**	**	NS	NS	NS

NS - not significant.

adspersus), and sand lance (*Ammodytes americanus*). These species are commonly found in Buzzards Bay and are all nonresidents. Adult eels and young bluefish, terns, egrets, and herons enter the marsh sporadically to feed on the fish in these marshes.

The migration of young fish hatched or reared in the marsh to estuarine waters as well as the transient feeding of deeper water fish such as bluefish and striped bass on marsh residents provide mechanisms whereby the abundant productivity found in these intertidal wetlands is exported to estuarine food webs. These processes represent important components of the role and function of these wetlands in coastal ecology and provide a strong argument in defense of wetland protection and preservation in the coastal landscape.

Ribbed mussels *(Geukensia demissa*, formerly *Modiolus demissus*) are frequently found in the intertidal wetland areas around the bay, generally growing abundantly in the peat around marsh grasses, and are most prevalent in the lower elevation areas of creekbanks where tidal inundation is greatest. This mussel is important in the ecology of coastal wetlands. Mussels are active filter feeders, straining all types of particulates out of the water column, ingesting the edible and processing the inedible into pseudofeces that accumulate around the mussel in areas where tidal currents are not sufficient to sweep them away. Average rates of biodeposition in the form of pseudofeces for the ribbed mussel is 549 g/year (Davis 1985). These mussels can actually bury themselves in these pseudofeces and in some areas must continuously migrate upward over time. This phenomenon results in the marsh acquiring a hummocky appearance with the height of the hummocks being limited to the level at which the mussels can still extract enough food from flooding tidal waters to survive (Teal and Teal 1969). In addition, the network of

Table 4.10. Average biomass and release of ammonia into marsh waters during summer by major marsh organisms. Biomass of mollusks excludes the shell weight; plant biomass aboveground only. Excretion proceeds for 12 h/day for *Geukensia,* 24 h/day for other species. Data from Jordan and Valiela (1982).

Species	Biomass (kg)	Release (μg NH_3-N/h/kg)	Release (kg NH_3-N/day/kg)
Bivalves			
Geukensia demissa	8,900	42	4.5
Mercenaria mercenaria	1,800	42[a]	1.8
Mya arenaria	1,000	30	0.73
Gemma gemma	460	42[a]	0.46
Grasses			
Spartina alterniflora	130,000	0.90	2.8
Spartina patens	3,600	0.42	0.4
Fish			
Menidia menidia	240	180	1.1
Fundulus heteroclitus	490	65	0.76
Fundulus majalis	120	160	0.47
Arthropods			
Uca pugnax	3,600	11[b]	1.0
Carcinus maenas	410	11	0.11
Orchestia spp.	140	11[b]	0.04
Snails			
Melampus bidentatus	460	19[c]	0.21
Ilyanassa obsoleta	55	19	0.02

[a]Excretion assumed equal to that of *G. demissa.*
[b]Excretion assumed equal to that of *C. maenas.*
[c]Excretion assumed equal to that of *I. obsoleta.*

byssal threads produced by these mussels increases the coherence of their substrate (Davis 1985) and may, along with belowground roots and rhizomes, stabilize marsh peat, especially areas along creekbanks. In areas with high levels of contaminants like polychlorinated biphenyls (PCB's) and metals in the water column (such as found in the Acushnet River estuary), the deposition of pseudofeces from filtration of organically bound contaminants increases the levels of these contaminants in the surface sediments of the marsh.

Studies by Jordan and Valiela (1982) indicate that ribbed mussels play an important role in the nitrogen cycle of coastal salt marshes. Nitrogen filtered but not deposited by ribbed mussels is excreted as ammonia or dissolved organic nitrogen, or used for production of flesh, shell, byssal threads, or gametes. The resident ribbed mussel population in Great Sippewissett Salt Marsh (West Falmouth) was found to maintain the highest biomass of any animal population, releasing more ammonia into the water than any population of plants or animals (Table 4.10), and accounting for 31% of the ammonia released into tidal waters during summer. Most of this ammonia is presumed to be taken up by phytoplankton or edaphic diatoms, bacteria, and fungi growing on *Spartina* detritus, as the overall ammonia concentration in tidal waters remains relatively unchanged. The population of ribbed mussels in Great Sippewissett was calculated to theoretically filter all of the water in each tidal cycle, although they presumably refilter water in their adjacent vicinity. Their biggest role in the nitrogen cycle of salt marshes is the retention of nitrogen within

the system through biodeposition of suspended particulate nitrogen. This is also true for other marsh species, *Mercenaria mercenaria, Mya arenaria,* and *Gemma gemma*; however, given the dominance of the ribbed mussel in this marsh, it is responsible for most of the total bivalve filtration and biodeposition. If the amount of particulate nitrogen filtered by these mussels was instead exported from the system, a significant loss of nitrogen to coastal waters would result. Because nitrogen limits phytoplankton productivity in Buzzards Bay, the increased nitrogen retention by ribbed mussel filtration may actually serve to reduce fertilization of adjacent bay waters.

In addition to their aesthetic value, the importance of marshes as storm buffers, habitats, and nursery grounds for numerous species, and historically as a valuable source of salt marsh hay, has long been a basis for defense in their protection. More recently, the role of salt marshes as nutrient buffers for coastal waters is becoming increasingly evident as our understanding of these complex environments continues to grow. This is especially true for areas such as Buzzards Bay where residential development is continually increasing.

Because marshes exist at the land and sea interface, questions arose in the late 1960's and early 1970's as to whether salt marshes were nitrogen limited, as are many coastal marine systems, or phosphorus limited, as are many terrestrial systems. Experiments undertaken to answer this fundamental question, most notably long-term fertilization experiments initiated in 1970 in the Great Sippewissett Salt Marsh, identified nitrogen as the nutrient limiting production in the salt marsh environment (Valiela et al. 1975; Teal 1986). Much attention has been paid in recent years to the role of nitrogen-limited salt marshes in intercepting or buffering nitrogen inputs from terrestrial sources as they move toward coastal waters. The increased understanding of marsh processes in this regard has contributed to the development of artificial wetland ecosystems (such as Solar Aquatics; Teal and Peterson 1991) for the tertiary treatment of nutrient-rich wastewater and septage. These new technologies hold promise for dealing with the often competing objectives of utilization and protection in valuable yet ecologically fragile coastal environments like Buzzards Bay. More information is available on salt marsh ecology in Teal (1986) and Nixon (1982).

4.2.2. Tidal Flats

Tidal flats are gently sloping unvegetated areas extending seaward of coastal landforms to mean low water (MLW). These flats are typically exposed at low tide, revealing sediments ranging from sands to muds and silts. Tidal flats are generally depositional environments, with the area and duration of exposure dependent on tidal amplitude. They are often associated with other types of coastal environments such as embayments, salt marshes, spits, and barrier beaches that provide a source of sediment for development of the flat.

Tidal currents in Buzzards Bay are primarily responsible for the sediment makeup of these flats. Along shorelines exposed to higher currents and wind-driven wave energies, such as along the edge of the bay proper, these flats tend to be made up of coarser, sandier sediments, while those flats in more protected areas, such as in estuaries, behind barrier beaches, or within wetlands or salt ponds, generally have finer, siltier sediments. Their association with other types of marine systems is important for providing both a source of strata and a source of allocthanous organic matter to the organisms that inhabit them.

Because the overlying water column retreats at high tide, only infaunal and epibenthic animals colonize tidal flats. At high tide, however, numerous species of fish "commute" to graze on the benthos and epibenthic algae. The infaunal communities inhabiting the tidal flats along Buzzards Bay provide a valuable resource to the aquatic food web and to the many species of waterfowl that feed on these organisms during low tide. Shorebirds, feeding primarily on invertebrates such as polychaetes, mollusks, and crustaceans, often follow the water's edge as it advances and retreats over the flats, with maximum foraging during low tide when most of the tidal flat is exposed. Many other species utilize the tidal flats, including crabs such as rock crab

(*Cancer irroratus*), green crab (*Carcinus maenas*), and blue crab (*Callinectes sapidus*); these species migrate on and off the flats with the tide, feeding on submerged bivalves and annelids. The lady or calico crab (*Ovalipes ocellatus*) frequently buries itself in the sandy sediments of these flats. Hermit crabs (*Pagurus longicarpus* and *P. pollicaris*) and snails (*Ilyanassa* and *Nassarius*) also coexist on the tidal flats; the hermit crabs utilize the empty shells of the snails for semipermanent homes. The horseshoe crab frequently uses the tidal flats as feeding and spawning grounds and deposits its eggs at the high water line. As with marshland, Westport has the largest areas of tidal flat and barrier beach within Buzzards Bay. Additional information on New England tidal flat communities can be found in Whitlatch (1982).

4.3. Terrestrial

The physical processes that formed Buzzards Bay not only led to a wide variety of marine environments but also resulted in a diversity of land forms, habitats, and natural resources within its upland regions. Human activities within the watershed area over the past several centuries, however, have significantly altered the structure and composition of many of these terrestrial systems.

Numerous kettle ponds, common to pitted outwash plains such as Buzzards Bay, are a dominant feature of the landscape. These deep ponds were formed when large blocks of ice left by the retreating glaciers were buried by glacial debris and outwash sands that collapsed as the ice melted, leaving the depressions. When the base of the depression was below the water table, a pond was formed. Many of these ponds support freshwater marshes, typically dominated by *Typha* and *Phragmites,* and provide important habitat for many species of animals.

Other freshwater environments within the Buzzards Bay watershed, like the freshwater marshes, are structured by the amount and duration of freshwater saturation. Critical habitats such as sphagnum bogs, cedar swamps, and vernal pools dot the landscape around the bay. Sphagnum bogs are similar to marshes in that they become established in areas of persistently saturated soils. These bogs are dominated by *Sphagnum* spp. or "peat" mosses and low-growing shrubs like cranberry (*Vaccinium macrocarpon*). The live sphagnum or peat mosses grow in thick mats overlying deep layers of accumulated peat. A very fragile system, these bogs often support a variety of rare and unusual plants such as wild orchids and carnivorous plants such as sundews (*Drosera* sp.). Sphagnum bogs can be found around the bay, notably in Falmouth (Chappaquoit) and Bourne (near the railroad bridge).

Like sphagnum bogs, cedar swamps, which are dominated by the Atlantic white cedar (*Chamaecyparis thyoides*), highbush blueberry (*Vaccinium corymbosum*), and swamp azalea (*Rhododendron viscosum*), occur in areas of saturated soils and acidic waters that affect decomposition and nutrient availability. The white cedar swamp is commonly found along with red maples (*Acer rubrum*), which often restrict the extent of white cedar growth. These cedar swamps can be found in pockets or associated with cranberry bogs around Buzzards Bay, in Bourne (east of the Bourne Bridge) and Falmouth (east of Woods Hole and east of Little Sippewissett Marsh in West Falmouth), but most notably in the Acushnet Cedar Swamp in New Bedford and Dartmouth, considered to be one of the last truly wilderness areas in southeastern Massachusetts. Cedar swamps, like huckleberry and maple swamps, were historically much more abundant but were cleared and diked to form many of the existing cranberry bogs, which is the dominant agriculture of the region (White 1870; Thomas 1990). Cranberry bogs require damp but not saturated soils for best production, conditions found in many of the swamp forests. Some attempts were made by the early settlers to conserve the white cedar swamps because their wood was used in the construction of moisture-proof foundations and for the cedar shingles prevalent on many houses in the region. The diminished availability of firewood with progressive deforestation, however, increased the

mining of peat from cedar swamps and, with the expansion of the cranberry industry in the 1800's, led to the near loss of this ecosystem from the watershed.

In the elevated areas around Buzzards Bay, the highly permeable soils of the region provide an ideal site for the growth of hardy species of oak (*Quercus* spp.), pitch pine (*Pinus rigida*), and white pine (*Pinus strobus*), the dominant trees of the region's forested land. Although somewhat small and "scrubby" (i.e., the name "scrub oak") by inland standards, these hardy trees reflect the low nutrient environment under which these forests have developed. Even with the encroachment of human development over time, these forests still support large numbers of wildlife, including deer (*Odocoileus virginianus*) and even coyote (*Canas latrans*). These woodlands have played an important role in the history of the region, yet the species we see today are not necessarily those viewed and utilized by the early settlers.

Significant changes have occurred in the bay's surrounding upland over the past several hundred years. In what is now primarily pitch pine-dominated forest, the landscape once supported significant stands of old growth forests of white pine, oak, walnut (*Juglans* spp.), beech (*Fagus grandifolia*), and holly (*Ilex opaca*). The extensive acreage of these original forests was frequently identified in the logs of early explorers and settlers (White 1870; O'Brien 1990). Although living near the sea, the early European settlers were predominantly farmers. Early on, they attempted to clear the forests for agricultural land with little understanding, and therefore regard, for the long-term impact on these virgin forests. These settlers were not the first, however, to impact the woodlands. Evidence in archeological records indicates that Native Americans typically practiced "slash and burn" techniques to clear the forests for the production of corn. Large-scale deforestation, however, occurred primarily from the late 1600's through the 1800's. Although many of the settlers shifted from farming to fishing, the cutting of the forests did not diminish. With fishing and whaling came shipbuilding, an important mainstay of the economy that increased the demand for wood for construction. There was also an associated demand for firewood to fuel the evaporation of seawater for preparation of salt and to boil whale blubber. About 1.5 cords of wood were required for producing only one bushel of salt (O'Brien 1990); at its peak, production of salt from Cape Cod was estimated at more than 1/2 million bushels per year (Fawsett 1990). In fact, the Sandwich Glassworks was established in the town of Sandwich not for its abundant sand (which was supposedly too impure) but for the extensive pitch pine and red oak (*Quercus rubra*) forests, which were cleared starting around 1825 and provided fuel for the glass furnaces for over 60 years, leaving the formerly well forested Sandwich hills basically bare.

The combined result of these various demands for wood was a general deforestation of the old growth forests all around Buzzards Bay, with only a few virgin areas now remaining; a notable example is a grove of white pine forest located in Beebe Woods, a forest preserve located just west of Falmouth center. After cutting, much of the woodland was left to natural succession. The relatively poor soil conditions that evolved after the destruction of the forests have led to reforestation by hardier species, notably the pitch pine, which grows widely in the region in those areas buffeted by wind and sea as well as on nutrient poor, sandy, barren soils. The survivability of this species also encouraged its widespread planting in the late 1800's so that with species of oak (scrub (*Quercus ilicifolia*), red, post (*Quercus stellata*), etc.), eastern red cedar (*Juniperus virginiana*, also known as juniper), and red maple, significant reforestation has occurred.

4.4. Unique and Threatened Environments

4.4.1. Anadromous Fish Runs

These fish runs are an important component of the fisheries of Buzzards Bay. Streams linking marine and freshwater bodies provide runs for several species of fish that grow to maturity in the ocean

and migrate to fresh water to spawn. Living primarily in salt water, anadromous fish such as alewives, blueback herrings, white perches (*Morone americana*), and rainbow smelts (*Osmerus mordax*) migrate up tidal streams to brackish and freshwater systems where, after spawning, the fry hatch and eventually return to the sea. Except for rainbow smelt, which migrate from February through April, migration begins in early March or April (when the water temperatures of inland rivers and streams begin to warm up relative to colder waters offshore) and generally continues into June. Anadromous fish typically return to the place where they were hatched, although it is not entirely clear how they identify any particular stream except perhaps by the unique water chemistry that may be associated with one area versus another. Anadromous fish runs within the Buzzards Bay watershed are shown in Table 4.11.

Successful fish runs have common characteristics: an unimpeded connection between creeks, ponds, lakes, rivers, or streams and the sea; sufficient volume and depth of flow to enable fish to overcome periodic obstructions within the run such as fish ladders, natural falls, or log jams; good water quality in the spawning area; and, of course, an availability of fish. Because fish in their early life stages are very vulnerable to fluctuations in their spawning or nursery environment, relatively constant environmental conditions such as temperature and salinity can be important to successful recruitment. Industrial pollution also has local impacts on anadromous fish, such as in New Bedford Inner Harbor where several historically productive

Table 4.11. Anadromous fish runs of Buzzards Bay. (From Massachusetts Department of Environmental Quality Engineering 1978.)

Town	River	Species	Spawning area
Falmouth	Herring Brook	Alewife, blueback herring	Wings Pond
	Wild Harbor River	Alewife	Dam Pond
Bourne	Herring River	Alewife	Little Herring Pond
Wareham	Sippican River	Alewife	Sippican River
	Agawam River	Alewife, rainbow smelt	Mill Pond
	Wankinco River	Alewife	Parker Mills Pond
	Red Brook	Alewife, blueback herring	White Island Pond
	Gibbs Brook	Alewife	Dicks Pond
Marion	Weweantic River	Alewife, rainbow smelt	Horseshoe Pond
Mattapoisett	Mattapoisett River	Alewife	Mattapoisett River
Acushnet	Acushnet River	Alewife	Sawmill Pond
Dartmouth	Slocums River	Alewife, rainbow smelt	Destruction Brook/ Russell's Mill Dam
Westport	Richmond Pond	Alewife	Richmond Pond
	Cockeast Pond	Alewife	Cockeast Pond
	Westport River	Alewife, brook trout	Westport River

fish runs have been all but eliminated. However, around Buzzards Bay it appears that simple impediments to migration by construction of dams without fish ladders or alteration associated with development, farming, or cranberry growing and even failure to maintain existing runs are the prime causes of declines of anadromous fish populations. Renewed interest in this fishery around Buzzards Bay in recent years, however, has resulted in increased attention to maintaining or improving the existing fish runs, and in reestablishing some of those lost through neglect or alteration.

4.4.2. Endangered Species

Some endangered and threatened species have been identified in the region of Cape Cod and the Buzzards Bay watershed (Table 4.12). To successfully preserve these species, it is necessary to preserve their habitats since the decline of many animal species is due to loss of nesting or ecological habitat. Species at the limits of their ranges are particularly sensitive as additional suitable habitat may not be readily available in response to alteration or destruction of existing areas. In addition to the obvious concerns over diminishing wildlife populations and decreasing habitat for many coastal species, indirect effects of activities in the coastal zone may also impact populations. The use of fertilizers and pesticides, for example, may affect areas far from the source of application. Beyond the direct impact of development, the mere presence of people may adversely affect the territorial behavior of many animals. Pets roaming free on the beach may act as predators and cause birds to abandon their nests. Stabilization of eroding dune systems near endangered nesting sites by "planting" used Christmas trees has been identified as problematic as they provide hiding places for many predatory animals. Even kite flying near ground-nesting birds can affect behavior because the kites are perceived as large avian predators.

Because the list of rare and endangered species (Table 4.12) is substantial and new species are being added, a species by species discussion is beyond the scope of this text. Several species, however, most notably avian fauna, are the focus of intensive, integrated, and highly visible protection programs and are briefly discussed.

Sandy beaches surrounding Buzzards Bay, notably Little Beach and Horseneck Beach on the bay's western shore, provide habitat for the federally listed piping plover (*Charadrius melodus*; Fig. 4.11). Piping plovers are indigenous to sandy beaches and have evolved a sand-colored body that is difficult to spot. Migrating from areas of the south Atlantic coast to northern Mexico, they arrive in late March and April and nest on the open beaches through August (O'Brien 1990). In the 1800's, piping plovers were extremely abundant but were hunted to near extinction by the early 1900's for the millinery trade. The Migratory Bird Treaty Act of 1918 provided the piping plover with some protection, and populations increased into the 1940's; thereafter, human disturbance and predation of nesting sites, primarily from development and increased recreational use of beaches, once again resulted in population decline. Recent surveys indicate less than a thousand pairs occur along the Atlantic Coast (D. Mignogno, U.S. Fish and Wildlife Service, Hadley, Mass., personal communication). Each nesting season, beach areas of active and potential nesting are cordoned off or fenced to exclude people and predators, and nesting success is followed and recorded to gauge population dynamics. Considered of "special concern" by the Massachusetts Natural Heritage Program and Endangered Species Program are least terns, whose nesting habitats—sparsely vegetated regions of the barrier beach above the high tide line—are similar to those of the piping plover. In the Buzzards Bay area, efforts undertaken to protect plovers are frequently expanded to include nesting habitats for least terns.

Buzzards Bay, specifically Bird Island located in Marion, also provides habitat for another federally listed endangered species, the roseate tern. These birds breed primarily on small islands and occasionally at the end of barrier beaches and build nests under or next to vegetation or some other object affording protection. Two distinct breeding populations are found in North America: one occurs along

Table 4.12. Rare plants and wildlife identified by the Massachusetts Natural Heritage Program and Endangered Species Program for the Cape Cod region including the Buzzards Bay watershed. From VanLuven (1991) and O'Brien (1990).

Species	Status
Plants	
Isoetaceae (quillworts)	
Isoetes acadiensis (Acadian quillwort)	Endangered
Ophioglossaceae (adder's-tongue ferns)	
Ophioglossum vulgatum (adder's-tongue fern)	Threatened
Schizaeaceae (climbing and curly grass ferns)	
Lygodium palmatum (American climbing fern)	Special concern
Alismataceae (arrowheads, water-plantains)	
Sagittaria teres (terete arrowhead)	Special concern
Poaceae (grasses)	
Aristida purpurascens (purple needlegrass)	Threatened
Dichanthelium wrightianum (Wright's panic-grass)	Special concern
Dichanthelium commonsianum (common's panic-grass)	Special concern
Dichanthelium mattamuskeetense (Mattamuskeet panic-grass)	Endangered
Diplachne maritima (saltpond grass)	Threatened
Elymus mollis (sea lyme-grass)	Endangered
Panicum philadelphicum (Philadelphia panic-grass)	Special concern
Setaria geniculata (bristly foxtail)	Special concern
Spartina cynosuroides (salt reed-grass)	Special concern
Spenopholis pennsylvanica (swamp oats)	Threatened
Cyperaceae (sedges)	
Carex oligosperma (few-fruited sedge)	Threatened
Carex striata (Walter's sedge)	Endangered
Eleocharis obtusa (ovate spikerush)	Endangered
Psilocarya nitens (short-beaked baldrush)	Threatened
Psilocarya scirpoides (long-beaked baldrush)	Special concern
Rhynchospora inundata (horned beakrush)	Threatened
Rhynchospora torreyana (Torey's beakrush)	Endangered
Scleria pauciflora (papillose nutrush)	Endangered
Araceae (arums)	
Orontium aquaticum (golden club)	Threatened
Juncaceae (rushes)	
Juncus biflorus (two-flowered rush)	Endangered
Juncus debilis (weak rush)	Endangered
Haemodoraceae (bloodworts, redroots)	
Lachnanthes carolina (redroot)	Special concern
Iridaceae (irises)	
Sisyrinchium arenicola (sandplain blue-eyed grass)	Special concern
Orchidaceae (orchids)	
Arethusa bulbosa (dragon's mouth orchid)	Threatened
Listera cordata (heartleaf twayblade)	Endangered
Platanthera dilatata (leafy white orchid)	Threatened
Spiranthes vernalis (grass-leaved ladies' tresses)	Special concern
Tipularia discolor (cranefly orchid)	Endangered
Polygonaceae (docks, knotweeds)	
Polygonum puritanorum (pondshore knotweed)	Special concern
Polygonum setaceum (strigose knotweed)	Special concern

Table 4.12. (continued)

Species	Status
Chenopodiaceae (saltworts, sea-blights)	
Suaeda americana (American seepweed)	Special concern
Portulacaceae (purslanes, spring beauties)	
Claytonia virginica (narrow-leaved spring beauty)	Threatened
Rosaceae (roses, shadbushes)	
Crataegus bicknellii (Bicknell's hawthorn)	Endangered
Linaceae (flaxes)	
Linum intercursum (sandplain flax)	Special concern
Linum medium (rigid flax)	Threatened
Empetraceae (crowberries)	
Corema conradii (broom crowberry)	Special concern
Hypericaceae (St. John's-worts)	
Hypericum adpressum (creeping St. John's-wort)	Threatened
Cistaceae (rockroses, frostweeds)	
Helianthemum dumosum (bushy rockrose)	Special concern
Cactaceae (cacti)	
Opuntia humifusa (prickly pear)	Special concern
Melastomataceae (meadow beauties)	
Rhexia mariana (Maryland meadow beauty)	Threatened
Haloragaceae (water-milfoils)	
Myriophyllum pinnatum (pinnate water-milfoil)	Special concern
Apiaceae (parsleys, angelicas)	
Hydrocotyle verticillata (saltpond pennywort)	Special concern
Gentianaceae (gentians)	
Sabatia campanulata (slender marsh pink)	Endangered
Sabatia kennedyana (Plymouth gentian)	Special concern
Asclepiadaceae (milkweeds)	
Asclepias verticillata (linear-leaved milkweed)	Threatened
Asclepias purpurascens (purple milkweed)	Threatened
Boraginaceae (borages)	
Mertensia maritima (oysterleaf)	Endangered
Scrophulariaceae (figworts)	
Agalinis acuta (sandplain gerardia)[a]	Endangered
Lentibulariaceae (bladderworts)	
Utricularia biflora (two-flowered bladderwort)	Threatened
Utricularia fibrosa (fiberous bladderwort)	Threatened
Utricularia subulata (subulate bladderwort)	Special concern
Caprifoliaceae (honeysuckles)	
Triosteum perfoliatum (broad tinker's-weed)	Endangered
Asteraceae (asters, composites)	
Achillea millefolium (seaside yarrow)	Threatened
Eupatorium aromaticum (lesser snakeroot)	Endangered
Eupatorium leucolepis (New England boneset)	Endangered
Gnaphalium purpureum (purple cudweed)	Endangered
Lactuca hirsuta (hairy wild lettuce)	Endangered
Prenanthes serpentaria (lion's foot)	Endangered

Table 4.12. (continued)

Species	Status
Wildlife (vertebrates)	
Fish	
Lampetra appendix (American brook lamprey)	Threatened
Acipenser brevirostrum (shortnose sturgeon)[a]	Endangered
Amphibians	
Hemidactylium scutatum (four-toed salamander)	Special concern
Scaphiopus holbrookii (eastern spadefoot toad)	Threatened
Reptiles	
Clemmys guttata (spotted turtle)	Special concern
Malaclemys terrapin (diamondback terrapin)	Threatened
Terrapene carolina (common box turtle)	Special concern
Pseudemys rubiventris bangsi (Plymouth red-bellied turtle)[a]	Endangered
Caretta caretta (loggerhead sea turtle)[a]	Threatened
Lepidochelys kempii (Kemp's ridley sea turtle)[a]	Endangered
Dermochelys coriacea (leatherback sea turtle)[a]	Endangered
Birds	
Podilymbus podiceps (pied-billed grebe)	Threatened
Botaurus lentiginosus (American bittern)	Special concern
Ixobrychus exilis (least bittern)	Threatened
Accipiter striatus (sharp-shinned hawk)	Special concern
Circus cyaneus (northern harrier)	Threatened
Haliaeetus leucocephalus (bald eagle)[a]	Endangered
Gallinula chloropus (common moorhen)	Special concern
Rallus elegans (king rail)	Threatened
Charadrius melodus (piping plover)[a]	Threatened
Bartramia longicauda (upland sandpiper)	Endangered
Sterna antillarum (least tern)	Special concern
Sterna dougallii (roseate tern)[a]	Endangered
Sterna hirundo (common tern)	Special concern
Sterna paradisaea (Arctic tern)	Special concern
Tyto alba (common barn-owl)	Special concern
Asio flammeus (short-eared owl)	Endangered
Ammodramus savannarum (grasshopper sparrow)	Special concern
Parula americana (northern parula warbler)	Threatened
Pandion haliaetus (osprey)	Special concern
Mammals	
Halichoerus grypus (gray seal)	Special concern
Wildlife (invertebrates)	
Bivalvia (mussels and clams)	
Leptodea ochracea (tidewater mucket)	Special concern
Ligumia nasuta (eastern pond mussel)	Special concern
Hirudinea (leeches)	
Macrobdella sestertia (New England medicinal leech)	Special concern
Odonata (dragonflies and damselflies)	
Aeshna mutata (spring blue darner dragonfly)	Endangered
Anax longipes (long-legged green darner dragonfly)	Special concern
Enallagma carunculatum (bluet damselfly)	Special concern
Enallagma laterale (lateral bluet damselfly)	Special concern
Enallagma recurvatum (barrens bluet damselfly)	Threatened

Table 4.12. (continued)

Species	Status
Lepidoptera (butterflys and moths)	
Fixsenia ontario (northern haristreak butterfly)	Special concern
Speyeria idalia (regal fritillary butterfly)	Endangered
Abagrotis crumbi banjamini (coastal heathland cutworm)	Special concern
Apharetra purpurea (blueberry sallow moth)	Threatened
Bagisara rectifascia (straight lined mallow moth)	Special concern
Catocala herodias gerhardi (Gerhard's underwind moth)	Threatened
Cicinnus melscheimeri (Melscheimer's sack bearer moth)	Threatened
Cingilia catenaria (chain dot geometer moth)	Special concern
Hemileuca maia (barrens buckmoth)	Threatened
Lithophane viridipallens (pale green pinion moth)	Special concern
Metarranthis apiciaria (coastal swamp metarranthis moth)	Special concern
Oligia hausta (northern brocade moth)	Special concern
Papaipema stenocelis (chain fern borer moth)	Special concern
Papaipema sulphurata (decodon stem borer moth)	Threatened

[a]Indicates species is federally listed as same status (U.S. Fish and Wildlife Service 1994).

a series of islands off the northeastern coast of the United States, from New York to Maine, and has smaller numbers of individuals extending as far as the Canadian Maritime Provinces; the second breeds on islands in the Caribbean Sea region extending from the Florida Keys and the Bahamas to the Lesser Antilles. Buzzards Bay represents an important locale for this species; approximately 60% of the northeast population nests on Bird Island in Buzzards Bay (1,650 nesting pairs in 1984; U.S. Fish and Wildlife Service 1989; B. Blodgett, Massachusetts Natural Heritage and Endangered Species Program, personal communication). As is true for the piping plover, the roseate tern population was significantly decreased in the late 1800's because of hunting associated with the millinery trade. The Migratory Bird Treaty Act of 1918 facilitated recovery of this species in the northeast to about 8,500 nesting pairs by the 1930's; however, the population decreased to roughly 2,500 pairs by 1977 because of increased numbers of nesting herring gulls and great black-backed gulls and increased human activities (U.S. Fish and Wildlife Service 1989). Extensive efforts have been undertaken to increase the species' nesting population and to expand the breeding range through a recovery program for the northeastern population. The goals of this program are to increase the species' nesting population to 5,000 pairs within at least six colonies in its current northeast range and hopefully effect an ultimate return to 1930's levels (U.S. Fish and Wildlife Service 1989).

Fig. 4.11. The piping plover (*Charadrius melodus*). Photo by D. Goehringer.

The osprey *(Pandion haliaetus)* is considered a rare bird whose numbers diminished throughout the United States during the 1950's and 1960's as a result of the widespread use of the pesticide DDT. The pesticide primarily affected ospreys by causing a thinning of the eggshell, rendering the eggs fragile and susceptible to disturbance or predation. Ospreys nest high above the ground, building large nests up to 2.4 m in diameter usually in large dead trees near the water, which provide them with easy access to their primary diet of fish. Human activities and development along the coast have resulted in the disappearance of many of these potential nesting platforms. Efforts all around Buzzards Bay to erect poles with nesting platforms have resulted in the return of many ospreys to the bay shores (Poole 1989).

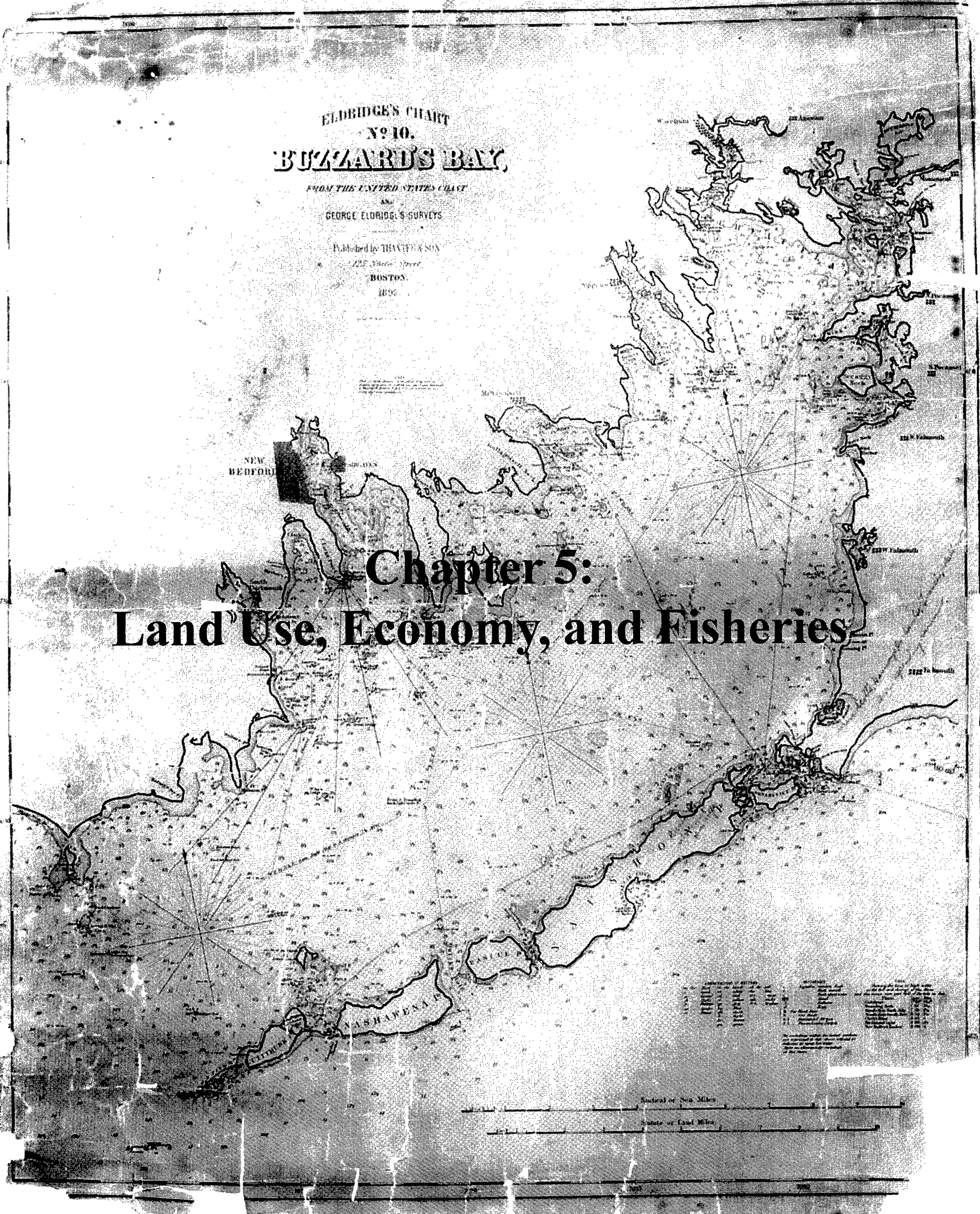
A nonavian endangered species under federal protection is the Plymouth red-bellied turtle (*Pseudemys rubiventris bangsi*), a subspecies of the red-bellied turtle of mid-Atlantic coastal plains. Only about 200 adults making up 12 populations are currently known, all within Plymouth County, which extends into the northeastern portion of the bay's watershed. Primarily a herbivorous freshwater reptile inhabiting freshwater ponds, the Plymouth red-bellied turtle requires a sandy substrate in the surrounding upland for nesting in late June and early July. Hatchlings emerge from late August through October, and survivors reach maturity at 8 to 15 years, females possibly later than males. While many factors have led to the decline of the Plymouth red-bellied turtle, possibly the most significant has been habitat losses both by direct destruction or indirect alteration resulting from land-use practices that prevent upland burning and decrease the availability of suitable nesting sites (Massachusetts Natural Heritage Program 1987).

There are a few strictly marine threatened or endangered species that use the bay; all are sea turtles. Federally listed species that frequent Buzzards Bay waters are the loggerhead (*Caretta caretta*, threatened), Kemp's ridley (*Lepidochelys kempii*, endangered), and leatherback (*Dermochelys coriacea*, endangered). These sea turtles visit the bay in summer after migrating from overwintering regions in warmer southern waters. Water temperature partially dictates their appearance because they lack the ability to regulate body temperature. Ridley and loggerhead turtles cannot withstand temperatures below 23.2° C and 19.5° C, respectively (O'Brien 1990), while the leatherback, which may have some thermoregulatory mechanism, has been found in colder northern waters (D. Mignogno, personal communication). The numbers of sea turtles frequenting Buzzards Bay are difficult to ascertain since their subtidal distribution makes sightings rare; however, 14 leatherback sea turtles were stranded around the bay from 1984 to 1987. Kemp's ridley sea turtle reports include three strandings in the early 1900's and a large number of sitings and strandings during a single event in the 1930's. Since the 1930's there have been no reports of further Kemp's ridley strandings (cf. Payne et al. 1994), although they have been occasionally sighted (Prescott in Camp, Dresser, and McKee, Inc. 1990). Only a single loggerhead has been found stranded in recent years (1985) within Buzzards Bay.

Use of Buzzards Bay by sea turtles is likely greater than suggested by the available sighting and stranding reports given the difficulty in seeing turtles at sea and the restriction against net fishing within the bay, which is a major source of sightings in other regions (cf. Payne et al. 1994).

Buzzards Bay does not present a habitat for significant utilization by either whales or dolphins. It appears that the absence of topographic and oceanographic features that concentrate prey species (and possibly the bay's shallow waters) are the underlying causes. A few individual sightings of cetaceans have been reported this century, though they tend to be near the entrance to Buzzards Bay, typically off Cuttyhunk, rather than within the bay itself (Payne et al. 1994).

Chapter 5: Land Use, Economy, and Fisheries



To evaluate water quality in coastal embayments, it is important to identify not only point sources of pollution discharging directly into the bay itself but also those inputs entering from the entire watershed. Nonpoint source inputs from the watershed are frequently less discrete and more difficult to quantify than point sources yet frequently last longer and potentially have more impact. This impact is especially true for nutrient inputs to coastal systems. To understand the variations in water quality throughout Buzzards Bay it is beneficial to look at the various land uses of the communities that make up the watershed as well as the economic factors influencing activities within and surrounding the bay.

5.1. Land Use

Many different land uses are found within the Buzzards Bay watershed; however, the relative dominance of land use patterns has been shifting in recent decades. Forested land represents the largest acreage in the watershed, followed by residential development. Agricultural (including cropland and pastureland), commercial, and industrial development make up the bulk of the remaining land uses. Over the past four decades, forestland area has decreased the most, closely followed by agricultural land, primarily due to the large increase in residential development. Commercial and industrial development has also been on the rise, primarily in response to the increase in year-round populations from new residential development and conversion of summer homes to year-round occupancy.

The changing patterns of land use within the Buzzards Bay watershed have had many consequences for the region, both environmentally and economically. Increased populations require additional services such as new or improved roads, adequate waste disposal, and increased utilities. The numbers of commercial enterprises such as stores, restaurants, and recreational facilities also increase. Increased development of watershed areas, especially in areas with on-site septic disposal of wastes (as is the primary method within the Buzzards Bay watershed), can create long-term problems with groundwater protection and can threaten the health of nearshore coastal waters through increased nutrient loading. The gradual loss of vegetated land surface to buildings, roads, or other paved surfaces affects many ecological processes, from the role of plants in the cycling of nutrients and water to the permeability of soils to precipitation. One of the greatest challenges facing land use planners and managers for the towns within the Buzzards Bay watershed is balancing these changing land use patterns with environmental protection. Maintaining this balance is important to ensure both a healthy environment and a healthy economy, with the health of the economy depending to a great degree on that of the environment, especially in this predominantly tourism-based region.

5.2. Economy

5.2.1. Towns Within the Watershed

The Buzzards Bay drainage basin includes 10 towns located directly on the bay, and 8 noncoastal towns located completely or partially within the watershed boundary. A brief description of these towns (Fig. 1.3), as they relate to Buzzards Bay waters, follows (information summarized from Buzzards Bay Project 1986, 1987, 1989, 1990; Camp, Dresser, and McKee, Inc. 1990; Terkla et al. 1990; personal communication with town representatives).

Coastal:

Westport. Westport is primarily a rural and agricultural community supporting much of the dairy industry within the Buzzards Bay watershed. In recent years, however, the town has experienced rapid residential growth. The Westport River, which actually comprises two rivers, the East and West branches, with independent subwatersheds, flows through parts of Westport and Dartmouth, with tributaries as far north as Freetown (East Branch) and Tiverton (West Branch). Both the East and West branches of the Westport River have relatively high water quality; however, increased numbers of closures to swimming and shellfishing because of high levels of coliform bacteria and evidence of

increasing nutrient inputs from residential development and upstream agricultural activities are of growing concern to the community.

Dartmouth. A relatively large town, Dartmouth includes the historic seaport village of Padanaram in its southeast corner. The town maintains a secondary treatment plant built in 1970 (to be expanded sometime in the 1990's) that discharges effluent into Buzzards Bay south of Salters Point. A portion of the watershed for the East Branch of the Westport River lies within the town's boundaries. Increased nutrient loading from development is a concern in this area; Lake Noquochoke, lying along one of the source rivers for the East Branch, currently suffers from eutrophication, with overproduction of aquatic plants due to excessive nutrient loading. Apponagansett Bay is also subject to high nutrient loads and resulting low oxygen conditions.

New Bedford. This city has the largest population in the region, with most of its land area (approximately 5,261 ha) developed. The Achushnet River (along the city's southeast border) has been heavily polluted by industrial and organic wastes. High levels of coliform bacteria, heavy metals, and polychlorinated biphenyls (PCB's) are found in the river waters and sediments. The sources of this pollution range from runoff and residential inputs in the upper portions of the river to direct industrial discharges and combined sewer overflows in the inner harbor (lower Acushnet River). From 1920 to 1973, wastewater was discharged directly into New Bedford Outer Harbor; since 1974 New Bedford has maintained a municipal wastewater treatment facility that continues to discharge primary effluent into the harbor, including storm-related wastewater. Also, there is a growing concern over the potential contamination of groundwater from the existing municipal landfill, which contains more than 225,000 kg of capacitors and barrels containing PCB's.

Fairhaven. As with many of the towns along Buzzards Bay, Fairhaven historically maintained a seaport. Bordering Buzzards Bay and the Acushnet River across from New Bedford, Fairhaven has experienced rapid residential and commercial growth in recent years. Fairhaven drains by the Acushnet River basin in the west, the Mattapoisett River basin in the northeast, and the Nasketucket River basin in the central portion of the town. Runoff of pollution from municipal and industrial sources into the Acushnet River has resulted in periodic low oxygen levels and high bacteria counts, exacerbated by inputs from treatment plant effluent and runoff from both New Bedford and Fairhaven.

Mattapoisett. Mattapoisett is a small coastal residential community. The town historically supported agriculture and shipbuilding but now is primarily residential with a seasonal influx of tourists during the summer months. The southern portion of the town drains directly into the bay through several small streams. Most of the town drains into the Mattapoisett River basin except for a small part in the northeast corner, which is part of the Sippican River basin. Mattapoisett River discharges into Mattapoisett Harbor; both have relatively high water quality without significant municipal or industrial discharges, although the harbor is occasionally closed for shellfishing because of high numbers of coliform bacteria. The source of this bacteria is primarily from discharge at the town pier of a small stormwater and sanitary collection system. High levels of nutrients and coliform have been measured in the stream that drains the center of the town, presumably from septic system leachate and domestic waste discharge. Runoff from nearby dairy farms is also identified as a source of pollution. Natural sources, however, cannot yet be ruled out.

Marion. Marion is a small rural community on the upper bay with a large seasonal influx of summer tourists. Most of the town's watershed drains directly to the bay through a series of streams and Sippican Harbor. Water quality has historically been high in all but a small portion of the Sippican River found to contain high mercury concentrations originating from the former use of mercury-based antifouling paints. Marion's wastewater treatment facility discharges into a small stream that enters Aucoot Cove. Studies conducted in Aucoot Cove, the recipient of the town's municipal wastewater treatment plant, indicate this area maintains relatively high water quality (Howes 1993). The former town landfill was graded and planted to reduce

leachate production and now serves as a waste transfer station.

Wareham. Located near the southern end of the Cape Cod Canal, Wareham contains significant areas of tidal wetlands through which three rivers, the Weweantic, Agawam, and Wareham, enter the bay. Wareham supports a large tourist industry with substantial commercial and retail activity. Intensive cranberry agriculture along the Weweantic River has historically resulted in problems with pesticide pollution. The river is often stagnant and occasionally experiences problems with low oxygen conditions; however, overall water quality conditions appear to be relatively good. Occasional fuel oil spills have occurred from business in Wareham Center. Buttermilk Bay, although receiving no known major point source discharges, is affected by nonpoint source discharge of nutrients from several nearby residential developments and historically has suffered from periodic eutrophication. Buttermilk Bay also experiences some oil pollution from the large number of boats that frequent this area. Onset Bay, immediately southwest of Buttermilk Bay, experiences much the same inputs from the substantial surrounding development. Cranberry growing is also prevalent in these areas, but studies of bog and bay exchanges indicate pollutant inputs from this source are small (Gill 1988; Howes and Teal 1992).

Bourne. Three-quarters of the population of Bourne resides within the Buzzards Bay watershed. The majority of developed land is residential with historic summer cottages now year-round homes. The town borders on Buttermilk Bay, an important source of soft-shelled clams that has been repeatedly closed to shellfishing since 1984 due to high levels of coliform bacteria. These waters also have provided an important area for scallop harvesting. Some areas, such as Barlow's Landing in the village of Pocassett and areas around Toby's Island, are also frequently closed to shellfishing because of high coliform bacteria numbers.

Falmouth. Primarily a residential community, the population of Falmouth increases from 27,000 in the winter to 63,000 in the summer. Tourism is a major economic resource, with tax revenues from tourist accommodations more than twice that of all the other towns within the Buzzards Bay watershed combined. Although some of this activity is located along the southern shore of the town, which is outside the bay's watershed, about one-third of this seasonal population increase is located within the watershed. West Falmouth Harbor has long been known for its high water quality and scallop fisheries; however, it is an area of future concern because it lies in the path of the groundwater nutrient plume generated by the Falmouth Wastewater Treatment Facility. The village of Woods Hole also lies within the Falmouth portion of the Buzzards Bay watershed.

Gosnold. The town of Gosnold actually represents the Elizabeth Islands made up of Nonamessett, Naushon, Pasque, Nashawena, Cuttyhunk, and Penikese islands. The 1990 census identified a population for Gosnold of 98 people, but even with the limited accessibility of the islands, the population does increase in summer with a small influx of tourists. Gosnold maintains no real manufacturing or industry, with the exception of a handful of small businesses serving the few residents.

Noncoastal:

Fall River. Fall River represents a major industrial city in the region, with a significant manufacturing center. Although locally important, only a small portion of the city resides within the Buzzards Bay watershed. The northeast corner of Fall River lies in the Westport River basin, and drains into the bay, with most of the city's discharge entering the Taunton River basin.

Freetown. Primarily a residential community, Freetown is situated between Fall River and New Bedford. Within the town's boundaries lies a 1,214-ha state forest, which has substantially contributed to the relatively undeveloped nature of this community. Its resultant nutrient input to Buzzards Bay waters is likely to be correspondingly small.

Lakeville. Lakeville is a small but growing town that has seen recent increases in residential development. The town includes several large ponds that provide fresh water for New Bedford and surrounding towns. Interest in maintaining high levels of

water quality in these ponds has focused attention toward protecting the quality of the surrounding groundwater to prevent contamination of these source ponds.

Middleborough. A large rural town, Middleborough lies partially within the Buzzards Bay drainage basin. The southeast corner of the town is in the Weweantic and Sippican drainage basins, which empty into Buzzards Bay. A substantial amount of Middleborough is preserved for watershed protection and conservation and does not provide significant pollutant inputs to the bay.

Rochester. Rochester is a rural agricultural community with limited highway access and subsequently little commercial or industrial development. The town is drained by the Sippican River on the east and the Mattapoisett River on the west. Although there are numerous cranberry bogs in the town, water quality remains high in the waters flowing towards Buzzards Bay. A regional trash incineration facility is located here that accepts trash from many coastal communities in southeastern Massachusetts.

Carver. Carver is a rural community with large areas of forest and about 40% of the cranberry bog area within the entire bay watershed (University of Massachusetts Cranberry Experiment Station, personal communication). Most of Carver is drained by the Weweantic River basin; southeastern Carver is part of the Winnetuxet River basin. To the north, the Winnetuxet River basin flows to the Taunton River basin, and the remainder of the town drains south to Buzzards Bay. Because it receives no municipal waste input, water quality is good in this river, with the exception of some areas identified to have pesticide residues from cranberry agriculture. The Wankinco River makes up part of the Carver-Plymouth boundary and maintains many impoundments as well as cranberry bogs. Except for some evidence of pesticide residues, this river is considered relatively clean as well.

Plymouth. This town maintains the largest land area in the commonwealth, sharing with Carver and Wareham the largest groundwater aquifer in Massachusetts. Plymouth has experienced substantial pressure for development of year-round and seasonal housing. Rivers from the watershed discharge primarily into Buzzards Bay, Plymouth Bay, and the Cape Cod Canal; the rivers flowing into Buzzards Bay have their sources in the Plymouth-Carver aquifer. These rivers include the Weweantic River, Wankinco River, Agawam River, and Red Brook, with Herring River discharging into the canal. The municipal sewage treatment plant for Plymouth discharges into Plymouth Harbor and Cape Cod Bay and therefore is generally not considered to influence Buzzards Bay.

Acushnet. The town of Acushnet supports a mixture of industry, residential development, and rural area and is located on the Acushnet River northeast of New Bedford. Runoff from the dairy industry has been identified as the cause of periodic low oxygen conditions and high coliform counts; although some reaeration of river waters is provided by a dam, this has no effect on the increased coliform populations identified downstream. Evidence of residual mercury inputs has been found, possibly from the historic use of mercury-based pesticides on nearby orchards (Terkla et al. 1990). Potential inputs from the municipal landfill to a tributary of the Acushnet River have been of growing concern in this area.

5.2.2. Economic Resources and Water Quality

For a coastal community, high water quality has both direct and indirect economic benefits. The health of valuable natural resources such as recreational and commercial fish and shellfish species depends on the environmental health of the ecosystem as a whole. For many coastal communities, tourism is also an important economic resource. Poor water quality seriously affects the desirability of a coastal area for tourism; it can also affect the value of real estate, which subsequently affects the revenue base for many of these towns. To evaluate the potential long-term impacts of declines in water quality on the local economy, it is important to differentiate between those changes caused by natural processes as opposed to human activities. In

some cases, activities aimed toward stimulating economic growth in coastal areas (such as increased development) can, if not planned with consideration for the potential long-term ecological impacts, ultimately result in decreased desirability and overall economic loss to the region. Environmental boundaries are more easily delineated than economic ones because the success of local economies is generally closely related to that of the surrounding region. In addition to local aesthetics, employment and business opportunities are important influences on the desirability of an area for development. Nearby metropolitan areas serve both to attract tourists and allow towns to serve as bedroom communities. In that much of the attractiveness of an area depends on its aesthetic appeal, it is somewhat ironic that the inherent beauty of the natural system may so often lead to its environmental decline. One of the primary challenges facing managers and land planners today is to maintain economic growth while ensuring environmental protection; this is difficult to achieve in that both objectives are affected by local as well as regional factors. This is certainly the case for Buzzards Bay, for within its watershed boundaries lies a wide variety of economic industries and natural resources, each affected to some degree by the other.

Identifying the sources of pollution and evaluating their potential impacts on the Buzzards Bay region are difficult because, although many point sources exist, the primary inputs are via nonpoint sources widely dispersed throughout the watershed. Another challenge lies in estimating the economic losses caused by pollution and the benefits of remediative measures, which often involve overlapping or widely separated political jurisdictions. Because rivers, streams, and groundwater are the transport mechanisms for many types of estuarine contamination, a pollutant's source may originate far from the resulting impact. Responsibility for monitoring, evaluating, and protecting water quality often lies simultaneously within different levels of government: federal, state, and local. The combination of these overlapping political, economic, and environmental boundaries often interferes with the efficient development and implementation of integrated environmental management and economic development plans. With pressures from development- and conservation-oriented interests, along with indications of potentially declining water quality in some areas of Buzzards Bay, increased attention is being given to the interrelationship between environmental and economic factors within the bay and its watershed.

A study of economic growth and environmental change in Buzzards Bay (Terkla et al. 1990) has identified population growth as the dominant factor currently affecting the environmental health of Buzzards Bay. The continued increase in residential development and tourism within the bay's watershed, as for most coastal communities, represents the leading cause of environmental degradation that is primarily due to increased eutrophication from increased nutrient inputs. This degradation may threaten the economic viability of some traditional agricultural and marine activities. Agricultural activities are likely to be more restricted as they are implicated as sources of contamination, while marine activities (fishing and recreational uses) are directly affected by water quality. Although the cost of lost revenues caused by poor or restricted fish and shellfish catch can be directly determined, the value placed on aesthetics and recreation is more difficult to quantify, even though these are the source of much of the current demand for improved environmental quality.

Terkla et al. (1990) reported that the Buzzards Bay watershed supports five primary economies: residential, manufacturing, tourism, agriculture, and fishing, all in some way influencing the health of the bay.

Residential. As with many coastal communities, the Buzzards Bay watershed has seen significant increases in residential development in recent decades, as evidenced by the changes in population. The region as a whole has seen an average increase of 31 people/km^2 since 1970, with 50% more housing units in 1988 than in 1980. This growth in the residential component affects the environment of the bay through increased use of on-site septic treatment of wastes and lawn fertilizers, the primary

nonpoint sources of nutrients (via groundwater transport) to the bay. In fact, only New Bedford and Fairhaven support significant public sewer systems, with most of the homes in the rural areas and much of the major towns of Falmouth, Bourne, and Wareham depending on private, on-site treatment (see Chapter 6).

Residential nutrient loading is magnified because many summer communities that were originally built close to bay waters and developed at high densities have been or are now being converted to year-round residences. Regulations frequently permitted this type of intense development with limited leaching field area (one-fifth of that required for year-round occupation) under the rationale that summertime water tables were lower, allowing for increased filtration of contaminants, and that the leaching fields would "cleanse themselves" during the balance of the year when not in use. Considering that nitrogen (a major potential contaminant to coastal waters) is not significantly altered in groundwater transport, the concurrent increase in nutrient loading as these summer homes are converted to full-time occupancy may substantially increase the potential for eutrophication in the bay's shallower coves and embayments without an obvious increase in housing stock.

The desirability of an area for residential development is dependent to a significant extent on aesthetics. Although most of Buzzards Bay and its associated coves and harbors are still relatively clean, increased frequency of eutrophic events and increased closures caused by coliform bacteria are becoming a factor. The towns surrounding Buzzards Bay face ever-increasing challenges to maintain the delicate balance between increased revenues from growing development versus the potentially significant economic impacts of overdevelopment.

Manufacturing. Traditional manufacturing industries around Buzzards Bay include textiles, printing, building materials, primary metals, and paper, as well as marine-related industries such as boat building and repair. In recent years manufacture of advanced oceanographic instrumentation, partially related to the proximity to Woods Hole research institutions, has become an expanding industry. With 8.3% of the area's total manufacturing jobs, instrument production is the third largest employer in the region, replacing older industries such as rubber, plastics, and primary and fabricated metals.

Although experiencing a decline, New Bedford remains the region's major manufacturing center, with 80% of the total related employment. Historic manufacturing practices severely impacted the environmental health of New Bedford Harbor, specifically the so-called "inner harbor," which had significant textile and metal-related industries. The production of electrical equipment and machinery, the second-largest manufacturing sector in New Bedford, has historically been a major polluter specifically to New Bedford Harbor. With new environmental regulations in the late 1970's, the two major electronics firms using PCB's were required to replace them with other materials. Because of their persistence in the environment, however, PCB's discharged into the Acushnet River and New Bedford Harbor still remain at levels well in excess of EPA guidelines in the water column (parts per billion vs. EPA standards of 1 part per trillion). Sediment contamination with PCB's has resulted in the closure of thousands of hectares to the harvest of shellfish and lobsters since 1979. Although PCB's have been replaced in the manufacturing industry, municipal wastewater continues to contain significant levels. Metal wastes from fabrication and primary metal industries contribute wastewater contaminated with heavy metals, acids, and other materials. Separation of metals "in-house" and land-based disposal of contaminated sludges have lessened the impact of these discharges on Buzzards Bay waters. Although Federal guidelines and discharge restrictions have reduced industrial waste inputs into Buzzards Bay, contaminants still continue to enter through the city's sewerage system. Because of the dominance of New Bedford as an industrial center, the environmental impact by industrial pollution to Buzzards Bay is largely confined to the Acushnet River and New Bedford Inner and Outer harbors.

Tourism. Tourism provides a major economic resource to Buzzards Bay communities, especially

the towns of Falmouth, Bourne, and Wareham. Those same qualities that make the Buzzards Bay region attractive for residential growth are also responsible for attracting tourists. Maintaining the natural resources on which the tourism industry is based requires a careful balance between protection of natural resources and accommodating the demands for access, especially to some of the most sensitive yet desirable areas. Employment in the two major tourist sectors, lodging and restaurants, has roughly doubled in the Buzzards Bay region since 1970, and the growth in tourist numbers has been even larger. With this surge in tourism comes a parallel increase in water activities such as boating, fishing, and shellfishing and growth in marine-related businesses.

The seasonal influx of tourists to communities in the Buzzards Bay region raises their populations by almost three-fold, increasing nutrient loading at a time when nearshore coastal waters are most susceptible to additional inputs. Parallel increases in recreational boating activities can increase turbidity in shallow, nearshore waters, decreasing light penetration with negative ecological consequences, notably the potential loss of valuable eelgrass beds. In addition, boat septic discharges add pollutants (although major efforts are underway to increase the availability of pump-out facilities and to restrict nearshore discharge), and small oil and gasoline spills are associated with power boat operation. The natural scenic beauty and recreational resources, as with most coastal environments, are in essence the basic cause of their own potential degradation by increasing the demand for access to these resources.

Agriculture. Cranberry growing is the dominant agricultural activity in the Buzzards Bay watershed, with dairy cattle farming second. There are 12 times more cranberry growers than dairy farmers, with economic revenues outstripping dairy production 30 to 1 (Terkla et al. 1990). Although both have been identified as potential sources of pollution to Buzzards Bay, recent evidence indicates that cranberry production contributes only very small amounts of toxic contaminants from pesticides (Gil 1988) and minimal amounts of nitrogen from fertilizers (Howes and Teal 1992). The dairy industry, however, is a major generator of fecal pollution through runoff, primarily in the Westport River area.

With increasing concern over excessive nutrient inputs, it is commonly believed that agriculture represents an important nonpoint source of these pollutants to coastal waters. In the drainage area around Buzzards Bay, cranberry growing is by far the largest agricultural land use, occupying some 2,695 ha around the head of the bay. Cranberry bogs are classified as wetlands; although highly modified from natural wetlands and managed so the plants are growing in well-drained soil, there are still periods when the soils are completely saturated (Fig. 5.1). Bogs, frequently created from swamps or low-lying areas, are sited near readily available water, usually with a stream flowing through them which then flows into coastal waters. Cranberry bogs are flooded during certain times of year, in conjunction with insect and disease control, harvesting, and frost protection. Although some of this water may be pumped back into reservoirs when the bogs are drained, eventually it all reaches the coast.

Cranberry bogs located within the Buzzards Bay watershed contribute about half of Massachusetts cranberry production. Although concentrated in Carver, Rochester, and Wareham (about 80% of the total hectarage in the watershed), bogs are

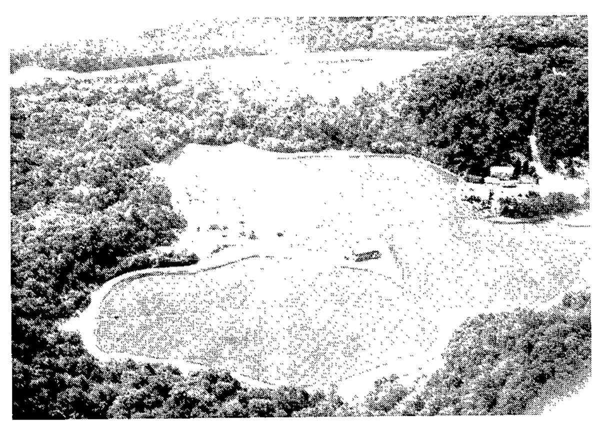


Fig. 5.1. Aerial view of a cranberry bog within the Buzzards Bay watershed. Photo by B. Howes.

predominant in the watershed contributing to the head of the bay (Fig. 5.2). Two primary methods are used in cranberry harvest: water harvesting, whereby bogs are flooded during the harvest season and the floating berries can easily be gathered on the surface of the water, and dry harvest, where the berries are mechanically scooped dry, which tends to damage the vines. The disadvantage of wet harvest is more rapid deterioration of the berries, with these generally processed for juice or sauce (90% of the national cranberry market). Dry-harvested berries are generally sold fresh or frozen, making up the balance of the market.

Cranberry cultivation has often been scrutinized for its potential as a source of pollution to coastal waters in that fertilization and pesticide application are common practices in this agriculture (Fig. 5.3). Increased demand for cranberry products has generally resulted in more efficient agricultural practices rather than overall areal growth, with chemical application methods becoming increasingly sophisticated to maximize yields. A constant concern has been the potential for coastal eutrophication resulting from nutrient losses through runoff and groundwater flow. However, measurements of inputs and losses from a major cranberry bog into the head of Buzzards Bay (Buttermilk Bay) indicate that losses are small, comparable to those generated by low-density (0.4 ha) residential development and certainly less than those of other dominant shoreline uses around the bay (Howes and Teal 1992). Nutrient retention by the bogs is consistent with crop management practices to prevent overfertilization, which tends to reduce yields by encouraging excessive vegetative growth. Generally, growers in the Buzzards Bay watershed apply only enough fertilizer to compensate for the nitrogen lost in berry harvest. Pesticides generally used in cranberry agriculture have been approved by EPA for application, and most have short life spans in the environment. With the increased use of recycled bog water (primarily due to limited water supplies), residual pesticides and nutrients are given additional opportunity to become sequestered within the bog before the potential for loss to adjacent coastal waters. Although fertilized, the bog loses about one-half to one-third of the amount of dissolved inorganic nitrogen (DIN, a readily bioavailable form of nitrogen) per unit area compared to detailed studies of a natural wetland, Great Sippewissett Salt Marsh (Valiela and Teal 1979). The pattern of loss is roughly the same for both systems, with greatest losses occurring during the coolest parts of the year when the receiving coastal waters are less sensitive to inputs.

The dairy industry has been identified as a potentially important source of agriculturally based pollution to Buzzards Bay waters. The towns of Carver, Rochester, and Westport are the primary sites within the watershed, with only Westport located directly on the bay. All of these towns have seen a decrease in agricultural activities in recent decades as residential development has replaced farmland. Of the three towns, Westport supports most of the dairy industry, although it has declined by more than half in the past two decades. However, closures of shellfish areas because of bacterial contamination have become more frequent even while the total number of dairy cows has decreased because the density of cattle per hectare in many areas has increased. The greater density has increased manure concentrations in some places, causing higher inputs in runoff from pastures and feedlots to streams entering the river and bay. As more land is converted from agricultural to residential housing, pollutant inputs from the dairy industry will be replaced, most likely with somewhat different but nevertheless significant inputs from humans.

Marine Economy. The marine economy in Buzzards Bay consists primarily of commercial finfishing and shellfishing, although commercial finfishing is prohibited in the central bay. Much of the commercial fishing fleet is based out of New Bedford, with most fishing activities concentrated offshore. The shellfishing industry, however, is centered primarily within Buzzards Bay. Four major species of shellfish are harvested—quahogs (or hard-shelled clams, *Mercenaria mercenaria)*, oysters, soft-shelled clams (or steamers), and bay scallops (see also Chapter 4). Quahogs represent the largest portion of the shellfishery, yet significant numbers of the other major species are harvested each year.

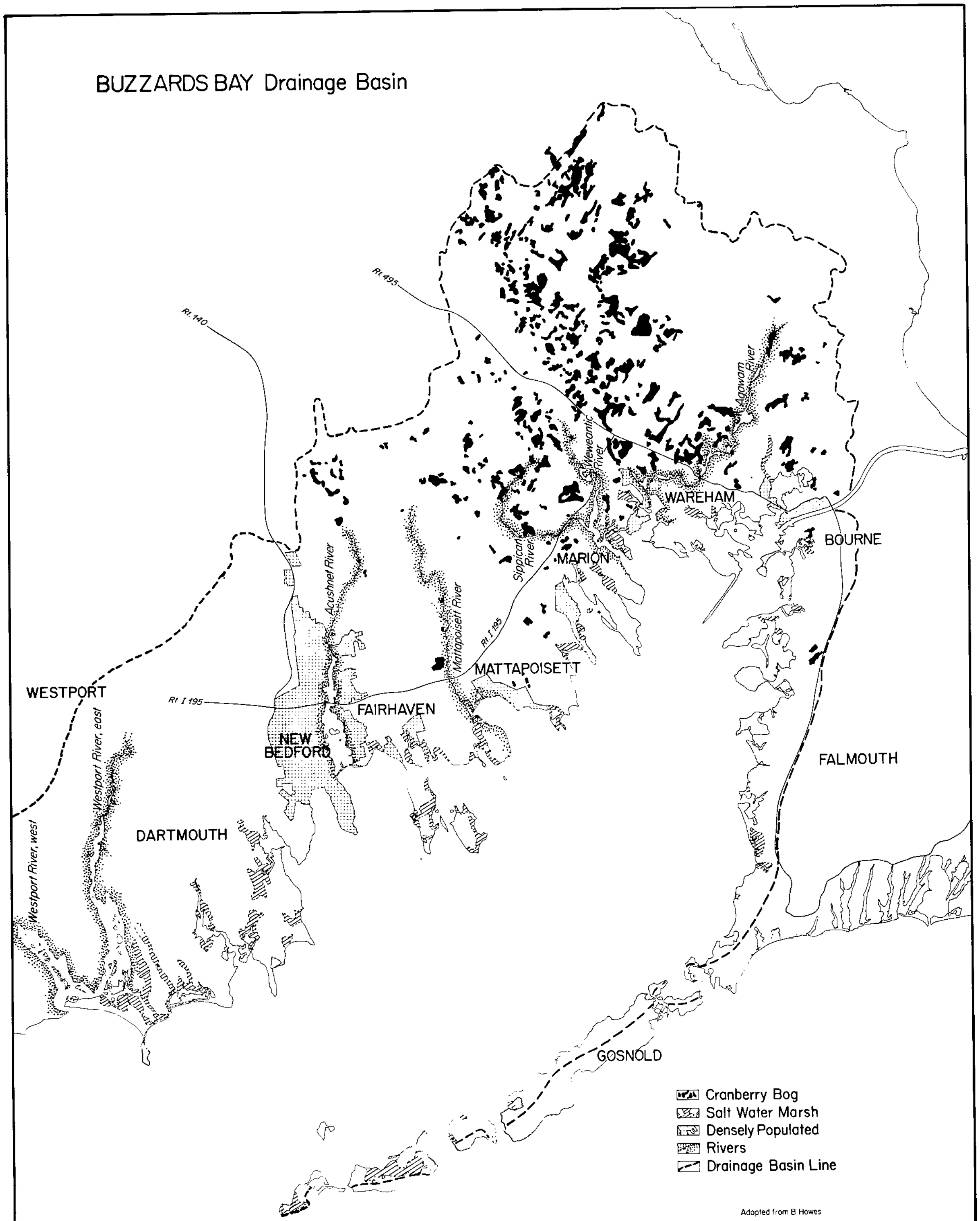


Fig. 5.2. Location of major cranberry bogs around Buzzards Bay.

Fig. 5.3. Spray irrigation on cranberry bogs, the primary method for application of fertilizer and pesticides, although flooding is also used for pest control. Photo by B. Howes.

As commercial finfishing is prohibited within Buzzards Bay waters, the marine economy most impacted by poor water quality conditions is the shellfishing industry. Unfortunately, only limited long-term information is available on local catches, and much of these data are of marginal quality for our purposes. The lack of information restricts our ability to look at long-term trends in economic losses caused by pollution or overfishing. Closures of shellfish beds because of coliform contamination, however, provide a general idea of the increased impact of anthropogenic activities within the watershed (cf. Chapter 6).

Although commercial marine activities do contribute some pollution to the bay, they also tend to be the most affected by pollution. This is particularly evident in the steady increase of shellfish bed closures caused by fecal coliform contamination, originating from road runoff, damaged septic systems, and wildfowl and other animal wastes. The average of 1,764 ha closed to shellfishing in 1970 has steadily increased, reaching an average of 4,452-4,856 ha in 1988 and nearly 6,070 ha in 1990. Although only a moderate portion of the overall shellfishery (primarily through recreational harvest), soft-shelled clams are particularly affected by bed closures since they are concentrated in areas most susceptible to bacterial contamination such as shallow nearshore embayments. The impact of the shellfishery (and recreational finfishery) on the marine economy is much greater than value of the annual catch because both support secondary industries and tourism.

5.3. Fisheries

Although early records of fish catches in Buzzards Bay are quite limited, it is clear that fish represent one of the most important resources of the bay. After the initial establishment of farming to ensure an adequate food supply, the early settlers turned toward the bay to supplement their diets. Salted and dried fish, primarily cod and mackerel, kept well and are frequently referred to in the historic literature, although many other species were also caught in the bay for immediate consumption. Schools of mackerel, bluefish, sea bass, butterfish, scup, and menhaden historically provided a significant catch in the deeper open bay waters (Belding 1916). In the late 1800's, the bay was also a source of menhaden, alewives, tautog, squeteague (also known as weakfish), and eels (Baird 1873). The extent to which Cape Cod's namesake, the codfish, was plentiful in Buzzards Bay waters is unclear; however, it has historically been part of the catch within the bay during late winter through early spring before it moves offshore during the warm summer months. The value of codfish to early settlers is evidenced by the fact that in 1639 the General Court of the Massachusetts Bay Colony ordered that these fish no longer be used as fertilizer. Cod landings for coastal Massachusetts vary widely, from a record high of 133,000 t in 1880 to 16,000 t in 1965, and 18,000 t in 1972 (Clayton et al. 1978).

Natural within-species variability compounds the difficulties with identifying long-term changes in fish populations within Buzzards Bay waters. For instance, scup were abundant when the early settlers arrived, notably from 1621 to 1642, but at some point toward the end of the century they virtually disappeared. They reappeared in abundance about 1794 and decreased again around 1864 but did not disappear completely (Baird 1873). Scup must have been an important resource, especially in the

late 1800's, as many petitions were introduced to control certain fishing methods to protect their apparently declining stocks. Often the declines of many fish species were blamed on the voracious and relatively nonselective feeding of bluefish, which are frequently found to have not only scup in their stomachs but also rock crabs, eels, sand lances, and a whole variety of other species. Remarks presented by a gentleman named Atwood at the 1870 Conference of the United States Commissioner of Fisheries stated that "all present" (including the commissioners of Rhode Island and Massachusetts) at those meetings agreed "scup, tautog, sea-bass and striped bass had within a few years diminished in Buzzards Bay," (Atwood 1820:117) but that overfishing was not a clear cause of this decline. These petitions also referred to concern over the threat of overfishing to mackerel. Mackerel are migratory and, swimming in large schools, provide a substantial catch if found. Their transient nature, however, made them somewhat unreliable as a sustainable fishery, and although mackerel were easier to cure than codfish, anglers were often more inclined to fish for other more dependable species. Nevertheless, mackerel were abundant, and their surface swimming behavior made them a frequent catch in fish weirs.

A representation of historical changes in catch compiled for the Buzzards Bay Comprehensive Conservation and Management Plan by Moss and Hoff (1989) is shown in Fig. 5.4. Records prior to 1920 indicated about 190 species of finfish spent some portion of their life cycle in Buzzards Bay. Unfortunately, few data exist from 1920 to 1960; however, for the post-1960 period 100 species of finfish have been identified. Combining the two periods, over 203 species of fish have been recorded in Buzzards Bay (Moss and Hoff 1989). This information indicates that Buzzards Bay fisheries were dominated previously by Atlantic mackerel, butterfish, silver hake *(Merluccius bilinearis)*, alewives, herring, and scup (Fig. 5.4). Today the most abundant fish species in Buzzards Bay are scup, winter flounder, and butterfish (Table 4.2). Bluefish, striped bass, and Atlantic mackerel are also seasonally prevalent in the bay, using it in summer and fall as a nursery ground. Young-of-the-year butterfish, sea bass, and scup numerically dominate the fauna each year.

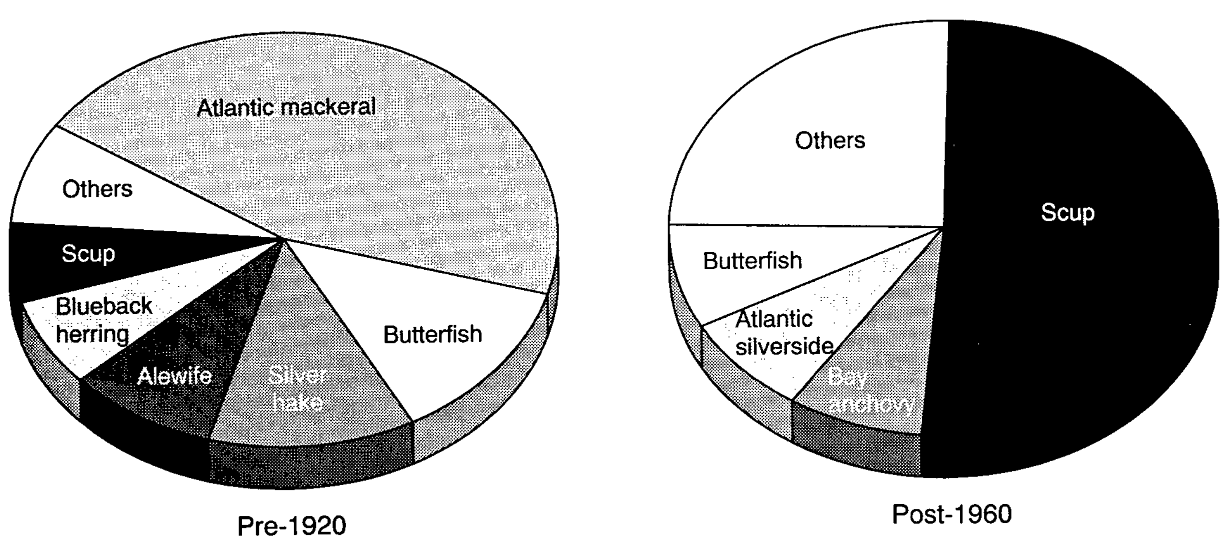


Fig. 5.4. Changes in reported fish catches for Buzzards Bay. From Buzzards Bay Project (1987).

The cause for the apparent species changes is unclear but may only reflect sampling differences from various fishing methods (i.e., traps vs. lines) and sampling locations as well as methods of recordkeeping (Moss and Hoff 1989). Trap fishing, for instance, was common before 1920 yet is not used to any great extent today. Although most of the species abundant in the pre-1920 data were present after 1960, there are some real differences in dominance. Shad, abundant in earlier years, are not abundant today (Davis 1989). Historic records disagree occasionally, as they do for instance with scup. Scup are identified as being important (but not dominant) before 1920 (Moss and Hoff 1989); however, substantial catches of scup were also reported in 1888, appearing in such numbers "as to bring down the price so that it hardly paid to ship them to New York" (Nye 1889:160). Also, testimony from Theodore Lyman, the Massachusetts Commissioner of Inland Fisheries in 1872, stated that "no representative (of the 'white fishes') has been more abundant on the south shore of Cape Cod than the scup" (Lyman 1872:112). Lyman attributed the decline in scup populations in these waters, including Buzzards Bay, to want of food, traps, and bluefish. He dismissed pollution as a cause, referring to the large numbers of fish and shellfish living in proximity to industries (Baird 1873).

Anadromous fish utilize Buzzards Bay for an important stage in their life cycle, the migration from salt water to brackish or freshwater areas for the purpose of spawning (see also Chapter 4). Several species dominate the anadromous fish populations in Buzzards Bay: alewives, blueback herring, white perch, rainbow trout (*Oncorhynchus mykiss*), and rainbow smelt. Of these, alewives have been historically dominant, most notably in the regions of the Acushnet, Mattapoisett, and Wareham rivers. Arriving earlier in the year than herring, alewives were usually caught for local consumption, with herring often exported (Wilcox 1887).

Blueback herring historically have been abundant in the bay; they were so plentiful that the early settlers would spread them on the land for fertilizer, a practice they learned from the Native Americans. The Pilgrims would bury two or three herring in each hill of corn, a practice known as "spot fertilizing." The success of corn cultivation by the early settlers was attributed to this practice, since no other source of manure was available to them. Many of the fields the Pilgrims worked had previously been cleared and cultivated by the Native Americans and had become depleted in nutrients. The herring were abundant, and the practice continued even after animals were imported from England, especially for corn, to preserve manure for other crops. As is true for alewives, herring were so important for food and fertilizer that laws were passed in the early 1700's to prevent grist mills, saw mills, and other water-powered industries from interfering with the upstream migration of these fish (Fawsett 1990).

The productive shellfish resources of Buzzards Bay have long represented a readily accessible and abundant source of food and income for residents living on or near the bay. The four primary shellfisheries are quahogs (or hard-shelled clams), scallops, soft-shelled clams, and oysters, with a relatively small fishery in surf clams and mussels (see also Chapter 4). The catch from recreational fishing of these species generally meets or exceeds that of the commercial fishery in all cases except for quahogs. Quahogs represent the largest commercial shellfish industry for Buzzards Bay, with commercial catch generally exceeding the catch of all other species combined (Table 5.1).

The hardiness of this bivalve with its rugged shell and ability to close tightly when disturbed or faced with low oxygen conditions results in a relatively long lifetime for individuals of this species. Littlenecks and cherrystones are the smallest of the allowable harvest, and they are favored for steaming, as well as for eating whole and raw. Chowder clams are generally chopped and used in chowders or other seafood dishes. Although catch statistics generally do not break down into size classes, each class maintains a somewhat distinct market (even though most methods of harvest do not discriminate among sizes). As the most important commercial shellfishing industry in Buzzards Bay, the steadily increasing harvests of this clam reflect their value to the

Table 5.1. Recreational versus commercial shellfish landings for Buzzards Bay by year (in kilograms). 1977-1982 data from Massachusetts Division of Marine Fisheries in Terkla et al. 1990 (data not available on bay scallops and surf clams); 1983-1990 data from Steven Cadrin, Massachusetts Division of Marine Fisheries, Sandwich, Mass.

	Quahogs		Soft-shelled clams		Oysters		Bay scallops		Surf clams		Mussels	
Year	Rec.	Com.	Rec.	Com.	Rec.	Com.	Rec.	Com.	Rec.	Com.	Rec.	Com.
1977	517,068	358,888	198,814	0	30,046	35,562	179,444	1,244,134				
1978	530,458	531,801	204,084	726	57,662	26,490	48,858	1,701,326				
1979	564,460	490,251	199,439	2,830	6,260	15,422	320,350	1,022,378				
1980	593,998	637,108	224,224	75,334	71,233	19,414	37,848	91,409				
1981	607,316	1,352,381	232,570	29,684	70,326	38,683	34,619	153,825				
1982	570,266	2,671,160	247,230	45,578	81,212	64,774	550,053	573,641				
1983	290,259	2,309,659	61,182	12,481	28,658	14,098	17,908	90,482	0	7,348	2,859	6,151
1984	125,479	2,209,204	85,585	43,524	13,608	92,453	5,906	69,466	1,497	44,144	2,722	4,191
1985	1,444,135	1,723,616	112,647	31,968	38,320	42,811	315,787	1,384,791	4,627	0	6,396	14,179
1986	476,089	2,044,956	119,315	83,771	30,945	42,947	10,777	29,393	0	0	4,491	4,844
1987	570,447	2,138,111	122,758	106,768	32,221	52,282	0	6,559	1,497	0	0	8,573
1988	438,749	1,474,046	96,445	75,660	17,609	45,233	0	816	163	0	136	490
1989	404,647	1,566,907	92,553	59,189	10,435	11,009	272	6,341	327	0	218	925
1990	316,114	1,079,268	55,069	109,675	3,388	0	0	1,959	272	0	272	1,170

fishery. They are the only one of the four major shellfish species found in water deeper than about 3 m. Before 1982, there were few deepwater quahog dredge boats in Buzzards Bay, with harvesting primarily conducted in shallow waters. The abrupt expansion of the deepwater fishery resulted in a large increase in quahog landings (Terkla et al. 1990), along with a parallel increase in landed value prices.

The highly prized bay scallop makes up an important fishery, especially in the shallower reaches of the bay. Although generally carrying a relatively high market price in comparison to other species, the significant year-to-year variability of scallop populations makes them a less dependable commercial resource relative to the more stable quahogs, soft-shelled clams, and oysters. The scallop has only one spawning season and is relatively short lived (only a couple of years on average); therefore, year-to-year populations can fluctuate substantially depending on the success of the previous set. In addition, scallops may grow to marketable size before they reach sexual maturity (Walsh et al. 1978), potentially reducing the number of individuals available for spawning (Capuzzo and Taylor 1979). The fishery began in the 1870's, focusing primarily on the western shore embayment of New Bedford and the Acushnet River; however, because of industrial contamination this area no longer provides the scallop resource of the past. West Falmouth harbor on the eastern shore has historically been an area of high scallop production. Increased interest and activity have been directed toward managing the scallop fishery in recent years, with attempts to increase natural production by transplanting or seeding scallops from productive beds and commercial hatcheries. The apparent decline in the population, as defined by the annual landings (Table 5.1), has all but removed this fishery from the bay in recent years; the cause of the decline is not known.

Oysters, being somewhat limited in distribution around the bay, represent only a small portion of the total shellfishery. Although found on both shores, oyster populations are not abundant. Anecdotal historical information and the presence of shell middens left by the Native Americans indicates oysters were once very prevalent in the bay. Most indications are that overfishing of this resource is the cause of long-term changes in the population, as supported by declining commercial and recreational catches over the past few years (Table 5.1). The apparently declining populations of this and the other shellfish species have resulted in attempts to seed areas such as New Bedford with stock from other areas within the bay. The requirement for suitable substrate for the settling of oyster spat has resulted in the establishment of new oyster beds in areas where artificial structures have been constructed, such as the spillway for the hurricane barrier in New Bedford Harbor.

One of the primary threats to the Buzzards Bay shellfishery (although not the shellfish) is the ever-increasing number of shellfish bed closures because of bacterial contamination. Routine monitoring of fecal coliform bacteria is conducted by the State of Massachusetts Division of Marine Fisheries; high levels of coliforms (greater than 14 colonies/100 ml) in a shellfish area will result in bed closure. Closure is done primarily to protect public health; however, the method has come under scrutiny in past years, as it does not necessarily reflect the ecological health of the environment. Coliforms are easily measured and although not directly harmful to humans are sometimes associated with other enteric pathogens harmful to human health. Shellfish bed closures that are due to the presence of coliform bacteria have increased dramatically over the past decade, paralleling the increased population growth experienced in the Buzzards Bay watershed (see also Chapter 6).

Although methods of estimating shellfish catch vary from town to town, total catch for Buzzards Bay in 1983 was estimated at over 91,000 bushels (36.3 kg/bushel). Of this, 76,000 bushels were commercial landings. In 1987, catch estimates increased to over 136,000 bushels, 94,000 of which were from commercial landings. This increase was in spite of declining fishable areas available due to increased closures from coliform bacteria. The value of the Buzzards Bay shellfishery in 1985 was estimated at

$6,575,000 (S. Cadrin, Massachusetts Department of Marine Fisheries, personal communication).

In contrast to their reputation as a high priced delicacy today, lobsters historically were so abundant they were considered "poor man's food." Records from the early days of the Plymouth Colony described occasional "plethoras" of the species thrown up onto the beach after a storm, sometimes several layers deep and often considered a nuisance. In some parts of the country, especially the south, lobsters were fed to the servants and slaves so frequently that a colonial Virginia government granted a petition that lobsters were not to be fed to these individuals more than twice a week. Cape Cod appears to be one of the first areas to actually pursue the lobster as a true fishery in its own right in the late 1700's; the well known Maine fishery did not support a lobster fleet until around 1940 (O'Brien 1990). What was once considered a nuisance species has now turned into a multimillion dollar industry (see also Chapter 4).

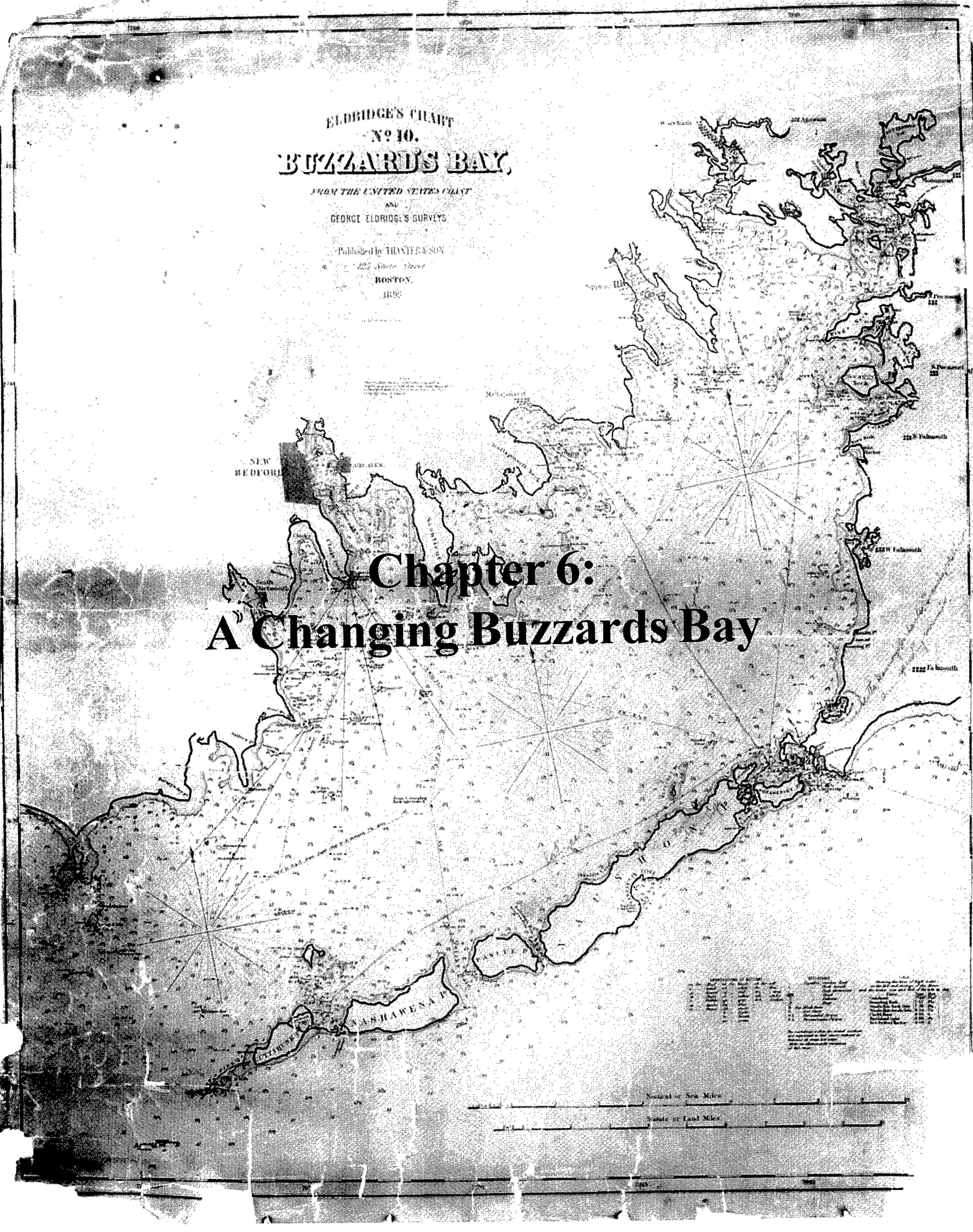
The reason for the apparent decline in lobster populations for the past few hundred years is not totally clear, but overfishing and in some cases coastal pollution are generally identified as the primary causes. In 1841 the average catch for Buzzards Bay was one lobster per day per pot. Today, the average catch per 3-day set is 0.8 lobsters per day (Davis 1989). Compared with 1841, today's rate of 0.8 lobsters per day per pot appears low, but the per unit catch in Buzzards Bay is still relatively high when compared to that of northshore fishing areas (Estrella and McKiernen 1988, 1989). Buzzards Bay today remains a very productive lobster area (Davis 1989). The lobster fishery originally began around 1807 along the Elizabeth Islands, primarily in Cuttyhunk. In 1880 the lobster catch from the New Bedford district (84, 155 kg) was as follows: New Bedford, 22,919 kg; Fairhaven, 20,412 kg; Mattapoisett, 1,361 kg; Dartmouth, 34,020 kg; and Westport Point, 5,443 kg. Lobster catch statistics from the period of 1981 through 1991 show the annual catch to be relatively stable over this period (Table 5.2) and similar to that of 100 years ago. The lobster fishery also provides a small recreational fishing industry. Lobster traps require some attention and must be checked frequently, especially in areas with higher lobster populations, to avoid cannibalism. In contrast to fishing, lobstering is not generally considered a recreational activity for the transient tourist; however, the increased demand for lobster in fish markets and restaurants around Buzzards Bay during the tourist season often results in inflated prices, frequently inspiring residents who do not routinely maintain pots to set out a few traps to catch lobsters for their own consumption.

Table 5.2. Commercial lobster landings for Buzzards Bay from 1981 to 1991. Data from Steve Cadrin, Massachusetts Division of Marine Fisheries, Sandwich, Massachusetts, personal communication.

Year	Landings (kg)
1981	97,088
1982	124,161
1983	144,033
1984	125,203
1985	107,653
1986	108,289
1987	113,298
1988	134,674
1989	143,401
1990	148,102
1991	131,868

Buzzards Bay is important to the regional lobster fishery as a productive spawning area and source of larvae for Massachusetts Bay via the Cape Cod Canal (Clayton et al. 1978; Davis 1989). The percentage of gravid females caught in 1987 in Buzzards Bay (31%) was significantly higher than those of regions north of Cape Cod. In comparison, areas north of Buzzards Bay maintained the following averages: Cape Ann, 4.5%; Beverly-Salem, 1.8%; Boston Harbor, 1.7%; Cape Cod Bay, 3.9%; and Outer Cape, 16.9% (Estrella and McKiernan 1988, 1989).

Chapter 6: A Changing Buzzards Bay



6.1. Human Impacts

Over the past several centuries, Buzzards Bay has experienced major shifts in both marine and land-based activities, many of which have affected the bay to some degree. Some of these activities have had a major impact on the utility and to some extent functioning of the bay, such as the construction of the Cape Cod Canal, yet have resulted in little environmental degradation to the system. Some activities, such as overfishing, were identified early on as potentially detrimental to the health of the bay, allowing sufficient time to implement management strategies. The impacts of other activities, however, are only recently beginning to be recognized, and our limited understanding of their long-term consequences hinders development of sound management policies to ensure protection of the system. Of these activities, the most recent focus of concern is the long-term effect of nutrient loading on the water quality of the bay.

Although water quality conditions in Buzzards Bay are still relatively good, some of the smaller circulation-restricted coves and inlets around the bay are experiencing declines. While PCB contamination and oil pollution present significant problems for the bay ecosystem, they tend to be localized (e.g., New Bedford Inner Harbor and Wild Harbor), with the major threat to Buzzards Bay aquatic resources being primarily from increased nutrient inputs. The growth in residential development and increased tourism are frequently identified as the causes for water quality declines, the long-term implications of which are still unclear. Periodic eutrophication events occur when increased nutrient inputs stimulate the overproduction of algae and phytoplankton, which, with dark respiration activities and decomposition, can result in oxygen depletion in these water bodies. The impacts of these nutrient inputs are greatest in shallow, circulation-restricted embayments, where lower rates of dilution and flushing are less effective in ameliorating the effects of additional inputs. In addition, stimulated growth of epiphytes on eelgrass as a result of increased nutrient loading can cause the decline of eelgrass beds, important in the production of bay scallops and other commercially valuable species. For a major estuarine system in the metropolitan corridor, however, the entirety of Buzzards Bay remains relatively pristine, still supporting a diversity of ecosystems, benthic communities, and fisheries (Tables 1.1, 4.1, 4.5, and 5.1). The goal for environmental managers will be to maintain the diversity and functions of the bay system as development continues.

6.1.1. Cape Cod Canal

The shallow waters off the easternmost shores of Cape Cod have historically claimed many ships and lives. Attention was often drawn to the narrow strip of land separating Cape Cod Bay from Buzzards Bay as a potential route to avoid these treacherous waters. This narrow, low strip of land, formed at the joint of the Buzzards Bay lobe and the Cape Cod Bay lobe of the Laurentide Ice Sheet, had two rivers that together nearly connected the bays. The Scusset River flowed northeast to Cape Cod Bay, and the Monument River southwest to Buzzards Bay, with only a few kilometers of low valley separating their headwaters. Early settlers discovered this trading route from the Indians, who used small boats to transport goods from Scusset River, hauling goods over land a few kilometers to the headwaters of the Manomet River and out to Buzzards Bay. Discussions were recorded as early as 1620 regarding the potential for a canal to be dug connecting these rivers, and three centuries later the Cape Cod Canal was constructed along nearly the same route; the history of the canal summarized here is extensively described in Farson (1993). By 1627, the use of the rivers even with portage became a popular route for Plymouth to trade with the communities along the Connecticut River and New York. Many initial planning attempts were made for constructing a canal, most notably when British warships blockaded the offshore route around Cape Cod in 1776 and later during the War of 1812. The project continued to flounder despite steady increases in shipping and shipwrecks, as well as an increased concern for future military defense. Several charters were granted, and there was even an initial start at digging by the Cape Cod Canal

Company in 1890. Each new proposed project was larger than the one before, and all had their own plans for dealing with the extreme currents that would be created by the differences in tidal range between the bays. Finally, work began in earnest in 1909 with plans to include locks abandoned in favor of a larger canal (primarily due to fear of freezing in the stagnant locks). Five years later the canal opened under private operation (Cape Cod Canal Company), and the waters of Buzzards and Cape Cod bays were joined.

The new canal was not without its problems; the swift current caused by its limited width (30.5 m) necessitated good maneuvering by ships, and many boats hit the banks of the canal. Frequently two large ships could not pass easily in opposite directions. During World War I, the canal received new attention in 1917 after a German submarine sank a tug and a string of barges off of Orleans (Cape Cod). The increased war-time shipping that resulted overburdened the canal's capacity, requiring the Federal Government to take over operations and perform emergency improvements and dredging. When World War I ended, the canal was sold to the U.S. Government, which began major expansion projects from 1932 to 1940, creating the system seen today. During this time, the canal was widened from 30.5 to 146 m at bottom level, making it the widest sea-level canal in the world. It was deepened to 9.8 m, and the approach channel was extended out to 28 km. The two highway drawbridges were replaced with fixed level bridges (the Bourne and Sagamore bridges), and a railroad drawbridge was replaced by a vertical lift bridge. Tolls were not charged for these bridges, yet the utility of the canal (foreseen in 1776 and 1812) was confirmed during World War II when German submarines routinely prowled the coast. The canal is now operated and maintained by the U.S. Army Corps of Engineers, Engineering Division, New England.

Although significantly improved after widening, the Cape Cod Canal still represents a significant navigational challenge. One of the major difficulties for shipping lies in the very strong tidal currents experienced throughout the passage. These currents result from the large differences in phase and amplitude of tides in Cape Cod Bay versus Buzzards Bay, with a mean tidal range in Cape Cod Bay of 2.8 m versus 1.2 m in Buzzards Bay. Currents maintain a regular reversal approximately every 6 h, the westerly current being the stronger (due to the higher tidal amplitude of Cape Cod Bay), with velocities averaging 3.5 knots (6.5 km/h), or 4 knots (7.4 km/h) during spring tides. The passage of large and small ships alike is closely monitored with extensive coordination, especially for larger ships such as tankers or cruise ships transiting the canal, to minimize the chance for accidents that threaten not only human safety but also the health of the environment.

6.1.2. Overfishing

Although it is often difficult to separate the impacts of overfishing from natural population variations as the cause for the declines in many Buzzards Bay fisheries, it is nevertheless clear that overfishing may be an important causative factor. Commercial finfish populations were already being overfished in the late 1800's with Baird (1873) attributing diminished fish populations in major part to the intense pound net and weir fisheries in southeastern Massachusetts. There were 30 weirs in the bay alone, whose shoreline covers only about 10% of the Massachusetts coast but accounted for 95% of the total Massachusetts menhaden catch in 1876 (Goode 1879). In an attempt to restore the population, net fishing was banned in Buzzards Bay in 1896, and the ban continues today. Unlike in most populated coastal regions where gill netting and trawling continue to deplete many fish stocks, the Buzzards Bay finfishery has been protected for nearly the last century.

However, the major present fishery, shellfish, has certainly been damaged by overfishing in many areas, specifically in nearshore areas. Nearshore shellfishing in Buzzards Bay functions more as aquaculture, with management practices undertaken over the past few decades to encourage healthy populations and allow depleted stocks to recover. Seeding programs are conducted, especially for quahogs, all around the perimeter of the bay, with beds closed

for periods to allow reestablishment of the population. To this end, an inadvertent advantage of shellfish bed closures due to high bacterial counts is that shellfish populations are left undisturbed and allowed to increase in size on their own, unimpacted, at least by human predation. Were it not for overfishing of the shellfish beds, seeding programs would generally not be necessary. The need for seeding programs to maintain the beds in many areas, however, signifies that the Buzzards Bay shellfishery has shifted more toward a cultivated rather than natural fishery.

Given the vast changes in fishing effort and the quality of catch statistics over the past 100 years, it is difficult to quantitatively evaluate the effects of overfishing on Buzzards Bay commercial species. Some general conclusions can be drawn for a few species, however. Shellfisheries form the best data base because they involve sessile populations and therefore can be thought of as local indicators. The major economic species of the late 1800's was the oyster, distributed throughout the bay's shallow waters. The evidence is fairly strong that for this species overfishing for at least 150 years following European colonization greatly depleted stocks, which remain so to this day. Freeman (1862:50) stated that oysters "formerly abundant and very large and finely flavored, have ceased" in parts of Buzzards Bay.

Goode (1887:272) reported that in the Westport River "an ancient bed of native oysters, which has now nearly disappeared through too great raking....not more than 50 bushels a year can now be caught throughout the whole three miles from the 'Point' up to the bridge." Compare this with roughly 400 bushels per year for the entire Westport River embayment from 1977 to 1987 (Terkla et al. 1990). Similarly, even Wareham, which was once reputed to have the "choicest brand" of oysters, supports few today. How much the lack of recovery results from the continuous fishing of a depleted stock (currently at 4,000 bushels/year) and how much from habitat destruction and disease is unclear, but the day of "oisters...a foot long...so bit it must admit of a division to be got in your mouth" (Wood 1634 as quoted by Goode 1887:731) are not likely to be seen again soon on Buzzards Bay shores.

Shellfishing historically has been conducted in the nearshore zone by the use of rakes and tongs, generally by individuals or small groups, which to some extent limited the catch by virtue of the limited energies of the fishermen. Although newer techniques are available, mechanization of the industry has been slow, mostly for ecological reasons, as the primary method available requires large-scale scraping of the bottom, resulting in significant damage to the system. New techniques such as hydrodredging, using forced water to uncover productive beds, have increased commercial catches in some areas; however, again the potential disturbance to the sediments has resulted in intense scrutiny and potential restrictions of this practice. Assessing the impact of overfishing on the scallop industry is more complex owing to the scallop's single spawning season and inherent natural variability. However, since scallops frequently reach harvestable size before reaching sexual maturity, the impact of overfishing on the already unstable population may have great consequences for future scallop populations within Buzzards Bay.

One important finfishery in Buzzards Bay dating to the earliest colonists is that for alewife. While overfishing by nets at inlets greatly reduced the population prior to 1896, today the harvest is again small compared to previous records. Much of this reduction is due to reduced demand and therefore reduced effort in catch (P. Brady, Sandwich Branch, Massachusetts Division of Marine Fisheries, personal communication), but it also appears to be a result of the lack of maintenance of "herring runs" or waterways, usually streams that lead from freshwater and brackish water ponds out to the sea. Historic waterways have been dammed, fish ladders have fallen into disrepair, pond flows have been altered by development, and natural processes that affect small flows in the coastal zone have all resulted in the decline of herring populations (D. Bourne, Woods Hole Oceanographic Institution, personal communication). Without a clear freshwater to saltwater pathway, which is required during

the life cycle of this species, population declines have been caused by physical obstacles rather than overfishing or chemical perturbation (see also Chapter 4). The alewife fishery is indicative of the variety of factors that may cause fish stocks to decline and underscores the need for sound biological data for ecological management.

6.1.3. Bacterial Contamination

Bacterial shellfish closures have been documented for Buzzards Bay since the early 1900's, primarily as the result of illness linked to the discharge of raw sewage. Unfortunately, bacterial contamination of shellfish beds in the early part of the century was generally identified only after resulting public health impacts were felt, with water tested after the outbreak of illnesses. For example, only after over 500 cases of typhoid fever were identified among shellfish consumers in New Bedford was it determined that substantial amounts of raw sewerage were entering New Bedford Harbor (Germano 1992). Significant restrictions were subsequently placed on the shellfishery, which led to the construction of a sewage system to collect all of New Bedford's sewage and discharge it farther into Buzzards Bay, the precursor to the city's current sewerage treatment system. It was not until 1925, when nationwide outbreaks of typhoid fever led the U.S. Public Health Service to develop a program for routine monitoring of bacterial contamination in shellfish areas, that other areas in Buzzards Bay, including parts of Mattapoisett Harbor and Apponagansett Bay in Dartmouth, experienced closures. By 1930 1,174 ha of shellfish beds had been closed. This figure remained relatively constant for years, increasing to approximately 1,700 ha in the 1960's, but with year-to-year variations caused by increased closures following major storms and hurricanes. In the 1970's shellfish bed closures increased significantly to over 3,238 ha; however, some of this increase is attributed to the increased monitoring effort undertaken during this time by the Department of Environmental Quality Engineering. This increase, however, was dwarfed by the substantial increase in closures during the 1980's to nearly 5,990 ha by the end of the decade, and 1992 closures averaged approximately 6,070 ha. The growing increase in closures during the past decade has had a significant impact on the shellfishery and has directed attention to the advancing ecological and economic threats posed by declining water quality conditions in some areas of the bay associated with sewage inputs (Fig. 6.1).

6.1.4. Toxic Pollutants

The variety of potential sources of toxic contaminants to Buzzards Bay are as wide as the variety of potential contaminants. Toxic chemicals, including petroleum hydrocarbons, PCB's, pesticides, organic compounds, and metals, can enter the bay through point and nonpoint source inputs from outfalls, runoff, rivers, streams, and atmospheric deposition. Chemical contamination from industrial activities primarily occurs in the urban areas of New Bedford, Fairhaven, and Dartmouth. Agriculturally derived chemical inputs (pesticides and herbicides), however, are more likely to enter through runoff and small rivers, which flow through virtually all of the bay's watershed, most notably the areas of Westport, Dartmouth, Fairhaven, and Mattapoisett (see also Chapter 5).

The most serious water quality problems involving toxic contamination in Buzzards Bay are focused

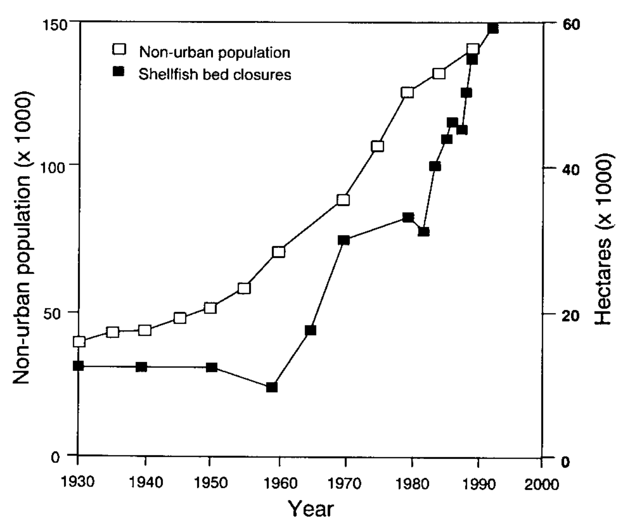


Fig. 6.1. Population versus shellfish bed closures for the Buzzards Bay watershed.

in New Bedford Harbor. Unregulated industrial discharges, primarily from two local manufacturers over many years, have resulted in high levels of several toxic pollutants in the sediments. PCB's, which were discharged into New Bedford Harbor and Buzzards Bay via the Acushnet River and from the New Bedford Wastewater Treatment Facility at Clarkes Point from 1947 through 1978, are major sources of concern. Heavy metals have also been introduced to the bay, again primarily at New Bedford, including copper, chromium, zinc, silver, cadmium, and lead. Sediment samples from outside New Bedford Harbor indicate a gradual spread of these contaminants. Fish and shellfish in the area continue to maintain high levels of these contaminants in their tissues. Because of the retention of these pollutants in the sediments, fishing and shellfishing in many areas will continue to be prohibited for years to come. In addition to any immediate toxic effects of these pollutants, their bioaccumulation can also seriously affect offspring, such as eggs and juveniles of winter flounder (Camp, Dresser, and McKee, Inc. 1990). This impact is not limited to resident species, but also affects migratory species that return to inshore spawning areas. In addition to the decreased viability of embryos, high concentrations of these compounds often reduce or delay spawning activity in adults (Bengtsson 1980; Black et al. 1988). The extreme difficulty and expense of removing, treating, and safely disposing of these compounds (notably the PCB's), however, has led to at least one recommendation that they remain in their present environment rather than being moved and reintroduced into a new area.

Other sources of toxic pollution to Buzzards Bay include stormwater runoff and landfills. Storm drains can often combine rainwater with oil and gas runoff from roads, chemicals from lawn fertilizers, and animal wastes from pets or wildlife. Landfills can be a major source of pollution from commercial and household toxic wastes that can leach into and contaminate groundwater and drinking water supplies.

Oil Pollution. Petroleum hydrocarbons enter Buzzards Bay waters directly through large and small accidental spills, waste discharges, and boating activities, and indirectly through stormwater runoff. There are no major point sources within the watershed, no production facilities, refineries, or petrochemical plants; about half of the oil entering the bay comes from oil "imports" to New Bedford, to meet demands for gasoline, heating oil, and industrial oil, and to the Boston region via the Cape Cod Canal. In fact, one of the major ecological effects of the canal stems from its use for oil transport resulting in periodic (1969, 1974, 1978) large-scale spills from oil barges traveling northward (Fig. 6.2). While the impacts of these spills are dramatic, they are also localized and account for only about half of the total oil entering the bay over the past 25 years. Small-scale spills from boats and fuel/oil harbor facilities, leaching from pilings, and outfalls account for less than 10% of the inputs. The largest chronic source, and the hardest to control, is runoff from residential, commercial, industrial, and road surfaces (SAIC 1991). There is another potential source of oil to bay waters, however, ironically from commercial fishing vessels and small recreational boats. Buzzards Bay supports about 4,300 moorings and slips and is the highway for more than 20,000 vessels per year. Recreational vessels discharge oil primarily as a function of outboard motor use, but it is the 200 or so fishing vessels that use 1.9-3.8 million liters of engine oil per year, much unaccounted

Fig. 6.2. Oil spill from the barge *Florida*. 1969. Photo by J. Teal.

for, that may represent a significant unquantified source to bay waters (SAIC 1991).

Our understanding of the effects of oil spills on coastal marine systems has been significantly increased through two of the oil spills in Buzzards Bay, which provided experimental sites for investigation of long-term ecological impacts. The chronic impacts of these oil spills (both occurring within the relatively short time frame of 5 years) have been monitored by researchers since their original occurrence and provide some of the only long-term data sets available on the persistence of aromatic hydrocarbons, the major constituents of oil and the compounds considered most damaging in the coastal environment.

On 16 September 1969, the barge *Florida* ran aground on a rocky shoal just west of Fassett's Point, West Falmouth, Massachusetts. Roughly 675,000 L of Number 2 fuel oil leaked into Buzzards Bay and were driven on-shore by strong south-southwest winds into the Wild Harbor River in North Falmouth. The oil spread over more than 400 ha, including 6.4 km of coastline, contaminating intertidal and subtidal bay areas and causing the death of many marine and salt marsh organisms. Much of the oil settled along a few meter band in the Wild Harbor Marsh, resulting in significant losses of benthic infauna and marsh grass, primarily *Spartina alterniflora*. Blumer et al. (1975) reported up to 95% of the benthic bay animals were dead or dying in heavily oiled areas 8 days after the spill; 16 months after the spill, areas with more than 1-2 mg oil/g sediment contained no living higher plants. Most of the fuel oil entering the marsh was sorbed into the anoxic marsh sediments with long-term chronic effects. Even in high marsh areas dominated by *Spartina patens*, oil was found to have penetrated at least 115 cm below the surface. In less contaminated areas where *Spartina* had nonetheless been killed, some regrowth of *Salicornia europaea* was evident (*Salicornia* sp. germinate well from seed and often recolonize damaged wetland areas until outcompeted by *Spartina*, which grows primarily from roots and rhizomes; Burns and Teal 1979). The abundant green algae (*Enteromorpha clathrata*) was highly contaminated, as was the less abundant red algae (*Polysiphonia fibrillosa*). These algae, along with *Spartina* and *Salicornia*, are the major sources of plant material to detritivores in these marshes. All of the organisms in the immediate area of the spill had oil incorporated into their tissues, including the fiddler crab (*Uca pugnax*), the marsh killifish (*Fundulus confluentus*), the ribbed mussel, and the herring gull. Fiddler crabs obtained most of their oil through feeding on mud, detritus, and algae; mussels and fish were probably contaminated through the processing of contaminated water; and the gulls were contaminated primarily from food. The effect of the spill on these organisms, although still evident, had lessened after 4 years. Although over 90% of the heavily oiled areas were considered "recovered" within 6 years, oil was still detectable in a subtidal mud core at 10-15 cm, and fuel oil hydrocarbons were present in some organisms near the contaminated salt marsh sites 20 years after the spill (Teal et al. 1992).

The greater recovery 5-20 years after contamination in subtidal areas versus marsh was due to offshore stations being affected by physical and biological processes that stir and weather the sediments, increasing physical removal and degradation of sorbed oil. The highly organic and reduced nature of marsh sediments and their low-energy environment limit physical removal and oxidation of introduced hydrocarbons. Twenty years later there was only limited evidence for oil hydrocarbons in existing marsh species, and that residue appeared to be a result from oil in less than 1% of the contaminated marsh area. Crabs, which burrow in the sediments and feed on detritus and algae, showed the greatest concentration of hydrocarbons in their tissues. Although present in only trace concentrations, these hydrocarbons still appear to be impacting the biota.

The other monitored spill that affected Buzzards Bay waters occurred on 9 October 1974, when the barge *Bouchard No. 65* hit a submerged object while travelling northeast into Buzzards Bay (Hampson and Moul 1978). The barge was towed to the west entrance of the Cape Cod Canal and anchored, leaking an undetermined portion of the original 11,604,810 L of Number 2 fuel oil into the

bay. As with the *Florida* spill, high winds and rough seas made containment impossible, and the oil was driven onshore onto Bassett's Island and Winsor Cove. A substantial immediate kill of marine life resulted, affecting crabs, snails, and clams; shortly thereafter marsh plants in Winsor Cove began responding as in the West Falmouth spill, with browning of *Spartina, Salicornia,* and the sea lavender (*Limonium*). Although plants were recolonizing the affected areas after 3 years, the recovery was slow and new growth limited in stem density and culm height compared with unoiled areas. Winsor Cove was more affected than other areas, as it received repeated applications of oil through tidal inundation and consistent winds. The marsh became impregnated with oil, and weathering was limited. The slow, chronic release of toxic aromatics from the buried oil impeded recolonization of plants and animals.

While the general focus will probably remain on the large and dramatic oil spills where there are obvious impacts, it is clear for Buzzards Bay and likely for most coastal waters that petroleum is entering daily, possibly at rates greater than those of the spills. Regardless of the source, all petroleum hydrocarbons combine to create the potential for cumulative chronic impacts to the aquatic systems of the bay, each with its specific sensitivity and capacity to retain or lose hydrocarbons.

Concern over the potential for significant environmental degradation from future shipping accidents has brought increased scrutiny to the regulations covering shipping through the Cape Cod Canal. Considering the hazardous nature of canal currents and the ecologically sensitive nature of Buzzards Bay, Massachusetts and federal regulations now require all foreign vessels and U.S. vessels sailing on register to be under the direction of a first-class pilot whose license is endorsed specifically for the canal and bay waters. In addition, beginning in 1992 a substantial effort was undertaken to remap the bay floor, primarily in response to several groundings in poorly charted areas around the bay.

Pesticides. The impacts of pesticides on the bay have greatly decreased since the banning of certain chlorinated pesticides such as DDT and dieldrin. During the 1950's and 1960's, these pesticides were frequently used for mosquito control within the watershed with detrimental results, most notably to resident invertebrate and fish populations (SAIC 1991). The pesticides routinely in use today (e.g., diazinon, parathion, cararyl), primarily for cranberry agriculture and mosquito control, are short lived and generally nonpersistent in the environment. As with most chemicals, however, excessive or improper application may have deleterious effects on animal communities, especially fish in small embayments; therefore, routine monitoring of these compounds is necessary to ensure protection of potentially susceptible areas.

Polychlorinated Biphenyls. Although minor inputs of PCB's enter Buzzards Bay from boat paints, dredged material disposal, and atmospheric inputs, the most significant input has been from manufacturing, primarily in New Bedford (Farrington and Capuzzo 1990; SAIC 1991). Contamination of New Bedford Harbor by PCB's represents the largest single source of toxic contamination in the bay because they were used since 1926 as insulation in electrical transformers and as coolants and lubricants. Significant inputs of PCB's occurred in the upper reaches of New Bedford Harbor from the 1940's to the late 1970's as a result of industrial waste discharge from several New Bedford firms that manufactured electrical components. Because these compounds do not break down into less hazardous chemicals, they pose a potential long-term problem to the ecology of Buzzards Bay and to the public health of residents who consume fish and shellfish from the region.

About 145 t of PCB's were discharged into the New Bedford-Acushnet River system between 1958 and 1977 (Farrington and Capuzzo 1990; SAIC 1991). However, with the decline in PCB release to the environment because of the development of alternative compounds and an active program to halt PCB discharge through the outfall, the primary present sources to Buzzards Bay are from resuspension of sediments in New Bedford Harbor and from atmospheric deposition. It appears that with the cleanup of the most contaminated

sediments in the harbor and the restricted circulation inland of the hurricane barrier at the mouth of the harbor, most of the PCB's will remain in harbor sediments and be buried by natural accretion. At present, the major source of PCB's to the bay proper appears to be by atmospheric deposition (Mayer 1982; Farrington and Capuzzo 1990; SAIC 1991).

In 1982, New Bedford Harbor was selected by the EPA for inclusion on the National Priorities List of the Nation's worst hazardous waste sites, making it eligible for Superfund cleanup funds. The site of contamination is large (over 400 ha), with the most serious contamination occurring near the head of the estuary, where PCB concentrations approach 30,000 ppm in the sediments. PCB's have been detected in the tissues of shellfish, lobster, and flounder, indicating mobilization of this contaminant through the food chain, primarily through the ingestion of contaminated sediments or contaminated prey (Fig. 6.3). Although the highest tissue concentrations are found nearest the site of greatest contamination, elevated concentrations have been found

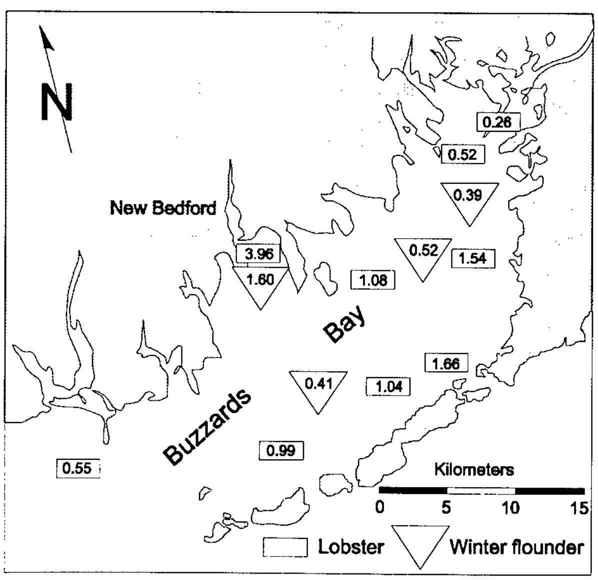


Fig. 6.3. Average PCB concentrations for lobsters and winter flounder collected at various stations around Buzzards Bay. Note the high concentration at New Bedford. Data from J. Schwartz. Massachusetts Division of Marine Fisheries, and Buzzards Bay Project (1987).

throughout the bay. The PCB's migrate from the highly contaminated bottom sediments into the overlying water column primarily through desorption, sediment resuspension by boundary layer currents, and through sediment reworking by benthic organisms. PCB contamination will be a hazard to the ecological health of New Bedford and Buzzards Bay for a long time.

Trace Metals. New Bedford Harbor is also the primary location for trace metal contamination within Buzzards Bay. Metals, including cadmium, chromium, lead, mercury, copper, silver, nickel, and arsenic, can enter bay waters through industrial waste discharge, boat paint, sewage effluent, and dredged material, as well as through atmospheric deposition and natural rock weathering. Industrial activities and the wastewater treatment facility in New Bedford, however, are dominant sources of these contaminants. Although industrial use of copper for metal plating, historically a large industry in the New Bedford area, is no longer prevalent, the use of copper-containing antifouling paints and copper pipes for water lines continues to input low levels of copper to the bay. Elevated concentrations of metals have been found in mussels, mummichogs, and winter flounder in New Bedford Harbor, as well as in ring-billed gulls and mice, indicating biomagnification of metals may be occurring through the food chain (IEP, Inc. 1988). Elevated levels of metals are found in the adjacent saltwater wetlands and in the detritivores and their predators living and feeding in these wetlands. As with PCB's, tissue concentrations are generally highest in areas nearest the areas of direct contamination (New Bedford Inner Harbor and near the outfall); nevertheless, mobilization of these metals is believed to be occurring through food chain transfer within the New Bedford Harbor system, as well as potentially to Buzzards Bay (Farrington and Capuzzo 1990; SAIC 1991).

6.1.5. Nutrients and Cultural Eutrophication

Although the basic ecology of much of the Buzzards Bay system remains relatively healthy and

pristine and in many ways similar to that experienced by early settlers in the region, there has been a major modification affecting the whole of the bay. This system-wide change involves nutrients, primarily nitrogen. In 1602 when Gosnold was sailing the waters of Buzzards Bay, the nitrogen inputs to the bay systems, especially in the shallow marginal areas, were substantially lower than they are today. Population increases (Fig. 1.5) of more than 100-fold from early colonial occupation to greater than 250,000 persons today are the primary causes for the increased loading, although regional development leading to increased atmospheric deposition of nitrogen has also been significant.

Nitrogen is a natural and essential part of all ecosystems, aquatic and terrestrial. For Buzzards Bay, as for most temperate coastal systems, nitrogen is limiting to phytoplankton, algal, and rooted plant productivity and therefore secondary production, especially shellfish. It would, therefore, seem that increasing nitrogen inputs would be a benefit to the system, increasing fisheries harvests. However, there is much current discussion about the problems associated with nitrogen loading to coastal systems and there are multimillion to billion dollar projects to reduce nitrogen loading to the coastal zone. The apparent paradox stems from the fact that at low levels of nitrogen in coastal waters, increased loading stimulates secondary production (e.g., fish and shellfish); at higher levels increased yields may still be achieved, but changes in community structure may begin to occur (e.g., phytoplankton species, benthic animal species, and impacts to eelgrass habitats). At higher loadings, however, the increased oxygen demand in the water column and sediments stemming from increased plant production exceeds the rate of oxygen input from photosynthesis and by atmospheric mixing, and lowered oxygen concentrations can occur (hypoxia, anoxia). It is the stress associated with low oxygen concentrations that has the most deleterious effects on plant and animal communities, and that at higher frequencies and durations results in the loss of stable populations and their replacement with opportunistic species. This sequence of nitrogen inputs leading to low oxygen concentrations in aquatic systems is called eutrophication, and when the nitrogen inputs are the result of human activity (as opposed to natural processes), the process is termed "cultural eutrophication." Cultural eutrophication is the greatest potential long-term threat to the Buzzards Bay ecosystem. While toxic impacts (e.g., oil spills) can have serious consequences, they tend to be relatively localized. The difficulty with managing nitrogen loading is its widespread distribution from a wide array of sources.

Current nitrogen inputs to Buzzards Bay include natural inputs from undisturbed areas, microbial nitrogen fixation, exchanges with offshore waters, and inputs due to development: directly through sewer outfalls, precipitation, and runoff, and indirectly through groundwater transport from septic systems, lawn and agricultural fertilizers, and animal farming. Although the population of the Buzzards Bay watershed has been increasing steadily since colonial days, only recently have significant signs of incipient cultural eutrophication become apparent in many of the embayments. One reason for this is that both the distribution and the total mass loading of nitrogen that determine the impact are related not to the rate of population increase but to the number of persons present. The population of the watershed has doubled this century (Fig. 1.5), but equally important has been the change in population distribution to a more widely dispersed occupation of the watershed surface.

The importance of the changing land uses and associated nutrient loading to the watershed, hence to bay waters, can best be evaluated by comparing the amounts and modes of input from the major sources. In addition, since there is no evidence that the "natural" sources of nitrogen have changed significantly over the past 350 years and since the assimilative capacity (the ability of the system to receive more nutrients without deleterious effects) has only recently been approached for most of the embayments, evaluation of "sources" will focus on the "new" sources related to human activities (i.e., the ones capable of being managed).

Point sources of nutrient pollution tend to be discrete and easily quantifiable, and nonpoint sources,

which are more widespread and more difficult to identify and measure, generally reach Buzzards Bay waters through groundwater transport. Point sources have historically been regulated and quantified, whereas nonpoint sources are a recent area of research and have a larger error associated with their estimates.

Point Sources. The only major point source of nitrogen in the Buzzards Bay watershed originates from sewage. Other potential point sources like major river discharges and large-scale agriculture do not contribute to bay waters (cf. Chapters 1 and 5, respectively). Residential and municipal wastes are piped to wastewater treatment facilities in the more heavily populated areas of the watershed. New Bedford, Wareham, Dartmouth, Fairhaven, Falmouth, and Marion maintain these facilities, and all except Falmouth discharge directly to bay waters (Table 6.1). The Falmouth facility discharges to groundwater by rapid infiltration and spray irrigation. Although the Falmouth facility attempts to lower nutrient loading (about 1% of the region's total) to coastal waters by adding a plant uptake and soil nitrogen removal step not used at the other facilities, the facility still "imports" nitrogen into Buzzards Bay because the contributing areas are outside of the bay watershed (Howes et al. 1992). In contrast, the Marion facility (less than 1% of total nutrient loading) discharges to surface water at the head of a salt marsh, which performs limited tertiary treatment before discharge to Aucoot Cove, and represents true removal (Howes 1993).

Table 6.1. Nitrogen inputs to Buzzards Bay from sewage treatment plants. Adapted from SAIC (1991).

Treatment plant	t N/year
New Bedford	962
Wareham	29
Dartmouth	57
Fairhaven	140
Falmouth[a]	15
Marion	7
Total	1,210

[a]Disposal by rapid infiltration and spray irrigation; transport through groundwater to West Falmouth Harbor, Buzzards Bay.

Almost all of the treatment facilities' input to the bay is in the New Bedford/Fairhaven area, with the New Bedford outfall and combined sewer overflows accounting for 80% of the total inputs from this source. The New Bedford outfalls (113.6 million L/day) serve 98% of the city's population plus 600 residences in Dartmouth and 60 in Acushnet. Thirty-eight sewer overflows contribute to the 962 t/year entering New Bedford Inner and Outer Harbors, discharging nutrients, coliforms, and toxics to bay waters. Combined sewer overflows are the focus of an ongoing remediation program (Camp, Dresser, and McKee, Inc. 1990); these discharges are responsible for restricted shellfishing in this area throughout this century. Sewage treatment plants and combined sewer overflows are the major source of nitrogen loading to bay waters, 1,210 t/year. These facilities service about half of the population of the bay's watershed and most of its heavy commercial and industrial area.

Nonpoint Sources. These diffuse sources of nitrogen to bay waters stem from residential waste disposal and fertilizer use, agricultural fertilizers, dairy and cattle farming, surface water runoff, and direct precipitation. In total, they represent slightly less than half of the "new" nitrogen loadings to the bay (Fig. 6.4).

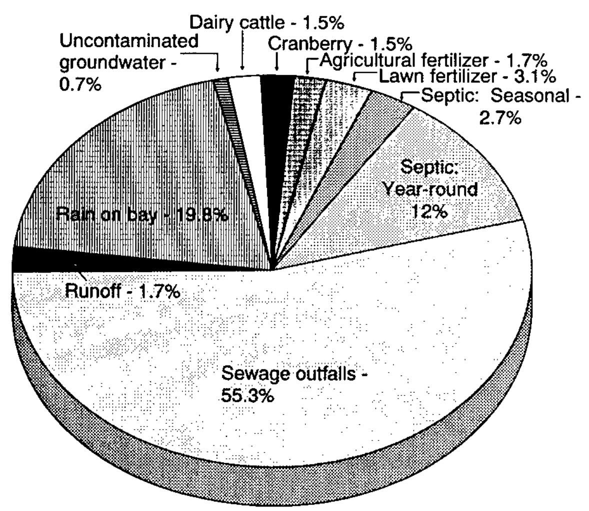


Fig. 6.4. Relative sources of nitrogen inputs to Buzzards Bay water. Note that wastewater (sewer and septic) accounts for two-thirds of the total annual input.

As might be expected from the outfall data, nitrogen from on-site septic treatment of wastewater is the major nonpoint source with a total contribution of 320 t/year. Nitrogen inputs from septic systems have been quantified within the Buzzards Bay watershed (Weiskel and Howes 1991) to calibrate loading models. Septic disposal treats the wastewater from almost half of the population, and with residential fertilizer usage (68 t/year) accounts for almost 80% of the nonpoint source nitrogen inputs originating within the watershed (i.e., disregarding input from precipitation). Both of these sources reach bay waters primarily by groundwater transport. Regardless of the original form of the nitrogen, the form of almost all nitrogen in groundwater is nitrate. For example, although both organic and inorganic nitrogen enter septic systems, as a result of degradation and anaerobic conditions within tanks almost all of the nitrogen released is as ammonium. Even at the very high resulting concentrations (millimolar), the ammonium is rapidly oxidized to nitrate by bacteria (nitrification) generally after a few meters of infiltration. Once the nitrate reaches the groundwater it is transported nearly conservatively (i.e., concentration changed only by dilution) to the bay shores (Weiskel and Howes 1992). Even where large treatment facility groundwater plumes occur the amount of removal from the groundwater is quantitatively relatively small compared to the loading (Smith et al. 1991).

Of the residential sources, septic system and fertilizers, the role of lawn fertilizers is more difficult to quantify because they are applied at low concentrations over wide areas. Estimates of lawn fertilizer application within the watershed are thus variable and subjective. Using data based on the number of dwellings per lot size (<0.1-0.2, and > 0.2 ha, with 279, 465, and 1,394 m^2 of lawn, respectively) a general application rate of 0.45 kg of nitrogen per 93 m^2 per year, and a 30% transport to groundwater, the estimated input of nitrogen is 68 t/year (SAIC 1991). An understanding of the role of lawn fertilizers is important for management, as they are a moderate-sized source but present an inexpensive trade-off for controlling nitrogen inputs when compared to removing nitrogen loading from septic systems or agricultural sources.

Agricultural inputs from cranberry bogs, dairy farms, and cattle, and miscellaneous crops account for the remaining land-based inputs (104 t/year). Cranberry growing accounts for relatively little nitrogen, about 33 t/year (Howes and Teal 1992), about the same as dairy farms and cattle or terrestrial croplands (Buzzards Bay Project 1990; Terkla et al. 1990). While they may be locally important sources of nutrients to the associated embayments, agricultural inputs do not represent a major source to the bay proper and are probably even smaller than stated since the inputs from dairy and cattle farming are based on the assumption of significant runoff in these permeable soils. The conclusion that low nitrogen loading results from agricultural practices is often hotly contested at the citizen and regulatory levels. The debate frequently arises from intuitive awareness that farming uses fertilizers and from omitting alternative uses of the land from the nitrogen loading equation. For example, while the total input from agriculture is from an area of the watershed about half the size of that covered by residential lots, its contribution of nitrogen is only about a quarter as much. The comparison with urban areas with sewage outfalls yields even greater contrasts. The sewered area of New Bedford represents much less than half of the total agricultural area of the watershed yet discharges 44% of the total nitrogen load to bay waters compared to less than 5% for agriculture (Terkla et al. 1990).

A frequently overlooked source of nitrogen to coastal waters is atmospheric deposition, either directly on the bay or via groundwater recharge. Atmospheric deposition takes two forms: dry (particle settling) and wet (dissolved in rainwater). The nitrogen in atmospheric deposition is about equally divided between organic and inorganic forms. In a study of nitrogen inputs to a Buzzards Bay salt marsh, Valiela and Teal (1979) found a total annual nitrogen deposition of almost 0.79 g/year at an average rainfall of 105 cm/year on each square meter of the watershed. Dissolved inorganic nitrogen deposition has been the topic of several regional

studies producing similar results. Because deposition to the bay surface is direct, it represents a major nitrogen input of 433 t/year; however, deposition also occurs on the watershed surface. In impermeable areas (roof top, paved surfaces, etc.) rainfall collects an additional nitrogen load that, if directed into bay waters or shunted to subsurface leaching pits, transports much of its nitrogen load (37 t/year) intact to the bay (Table 6.2).

Fortunately, most of the watershed surface is permeable and vegetated so that deposition on most of the surface is not washed off but enters the soil system where plant uptake and microbial nitrogen transformations can occur. In these areas, most of the nitrogen deposited from the atmosphere is removed in transport, being denitrified or held in organic forms in soil. The result is that the permeable areas with almost twice the deposition of impermeable areas represent less than 4% (16 t/year) of the total nitrogen delivery to bay waters. Comparing all of the nonpoint sources, atmospheric deposition accounts for almost half (46%) of the total loading. While some portion of this atmospheric deposition is certainly from within the watershed, the limited population and industry and the relatively small area involved indicate that most is probably due to the movement of nitrogen-contaminated regional air masses.

Boat discharges that place nutrient inputs directly into bay waters have not been quantitatively evaluated, but they represent a very small potential source. There are 4,300 slips and moorings associated with Buzzards Bay, but the vast majority are summer usage and typically occupied only a few days per week. In addition, pump-outs for boat wastes are available around the bay (the nutrients then becoming a part of the treatment facility inputs), and direct discharges are prohibited nearshore. The result is a potential input from this source less than 0.1% of the total loading to bay waters and an input distributed throughout the bay. Compliance with proper discharge procedures reduces this source to near zero. The problem with boat discharges appears to be more associated with bacterial and pathogenic contamination of the waters than with cultural eutrophication.

Comparisons of the various sources of "new" nitrogen to Buzzards Bay waters clearly indicate that disposal of human wastes accounts for most of the inputs (70%), with treatment facilities accounting for 55% and septic disposal 15% (Table 6.2). Of the remaining inputs, precipitation accounts for 22%, agriculture for 5%, and lawn fertilizers 3%. While each embayment requires its own nitrogen management scheme focusing on the site-specific sources and tolerances (Costa et al. 1994), it appears that the major management issues must focus on waste disposal.

The potential impacts of nitrogen inputs from treatment facilities and residential inputs, septic systems, and lawn fertilizers differ in several ways. First,

Table 6.2. Annual inputs of nitrogen to Buzzards Bay waters.

Nitrogen source	Nitrogen input (t/year)	% of total
Precipitation		
on bay waters[a]	433	19.8
runoff - developed surfaces[b]	37	1.7
groundwater (uncontaminated)[c]	16	0.7
Wastewater treatment plants[b] (Outfalls and CSO's)	1,210	55.3
Septic disposal of wastewater (groundwater contaminated)		
year-round[d]	260	12.0
seasonal[e]	60	2.7
Nitrogen fertilizers		
lawn[b]	68	3.1
agriculture (misc.)[b]	38	1.7
cranberry bogs[f]	33	1.5
dairy and cattle[g]	33	1.5
Total	2,188	100

[a]Surface area = 55,000 ha, 0.75 mg N/L (Valiela and Teal 1979); total Nitrogen (TN), 105 cm rain/year. TN was used since other inputs (i.e., outfalls) include dissolved organic Nitrogen + particulate organic Nitrogen pools.

[b]SAIC 1991 and Buzzards Bay Project 1990.

[c]Land area = 1,103 km^2 (SAIC 1991), 1.9 M in groundwater (Weiskel and Howes 1991), 54 cm recharge/year (Frimpter et al. 1990).

[d]Terkla et al. 1990; SAIC 1991; Weiskel and Howes 1991.

[e]20.1% seasonal (U.S. Census; Terkla et al. 1990), 155 mol N person/year (Weiskel and Howes 1991) and estimate of 4P, 4 mo/H (Herr 1984).

[f]2,695 ha bogs in watershed (Terkla et al. 1990) and 13 kg/ha/year (total bog export; Howes and Teal 1992).

[g]Terkla et al. 1990.

for more than 60 years in the distribution of the inputs, almost all of the treatment facility input to the bay has been from a single region, New Bedford/Fairhaven. The nutrient-related ecological impacts of these inputs have thus remained relatively localized (Howes and Taylor 1989; Costa et al. 1992). The result is that only a small portion of the bay has been degraded, although it is receiving almost half of the total loading to the entire bay. In contrast, over the same 60 years there has been a rapid rise in the nonurban population (Fig. 1.5), which uses septic waste disposal and is distributed primarily along the tributaries to the bay's shallow embayments. Although these systems in total receive lower loadings, they are shallow and poorly flushed and mixed, giving them a lower assimilative capacity; as a result, some are already exhibiting eutrophic conditions. It also appears that there is a much lower per capita nitrogen load from septic systems versus treatment facility disposal; both systems cover about the same population base but differ in contribution by four-fold. Part of this difference is due to additional nitrogen sources (commercial and industrial and combined sewer overflows) in the treatment facility fraction, but a major factor is the removal of particulates, sorption, and denitrification associated with septic disposal (Weiskel and Howes 1991). The particulates form most of the "septage" removed when tanks are cleaned (Teal and Peterson 1991), and the significant nitrogen that they contain is transported to a surface disposal site or is put through the treatment facilities.

The incipient cultural eutrophication of the embayments compared to the bay proper stems from their lower assimilative capacity and higher relative nitrogen loadings. Although almost all treatment facility discharges are to better flushed areas, the embayments receive nearly all of the other watershed inputs, so that while they receive less than 25% of the "new" nitrogen load, they occupy less than 14% of the area (75 km^2) and even less of the volume of the bay (calculated from Table 6.2). In addition, much of the watershed nutrient load first cycles through the embayment systems, which retain or remove some of the load, thus buffering bay waters. Unfortunately, it is these same embayments and nearshore waters that support the most diverse ecological habitats and productive fisheries, as well as much of the recreational and aesthetic values of the bay.

6.2. Natural Modification

The land-sea interface of the coastal zone is always in transition, especially landscapes like those surrounding Buzzards Bay, which are relatively recent and are composed of unconsolidated glacial till. In addition to the normal surficial weathering that operates on geologic time scales, two processes are altering the coastal zone on smaller time scales: relative sea-level rise (the level of the sea relative to the level of the land at any locale) and storms. Although these processes have been acting on Buzzards Bay throughout its existence, the apparent recent acceleration in the rate of relative sea-level rise has increased the rate of erosion and coastal regression to the point of easy observation in periods much less than a lifetime. Coastal storms act in concert with rising sea level; however, the two differ in that rising sea level is continuous and gradual and coastal storms are occasional but often dramatic.

6.2.1. Relative Sea-level Rise

There has been much recent concern over changing sea levels and the potential effects on the coastal zone; however, relative sea level has been constantly changing through geologic time. The relative level of land and sea can be modified by changing sea or ocean level (eustatic sea level) and by changing land level. There are many mechanisms that alter land and sea levels: changes in the volume of water in the oceans through changes in the volume of the ocean basins by plate tectonics and sea floor spreading, or even sedimentation or changes in land levels through tectonics or isostatic adjustment. While the whole variety of factors are at work in the world's coastal zones today, in Buzzards Bay two primary factors account for the rise in sea level

over the past several thousand years: subsidence of the land and changing oceanic or eustatic sea level.

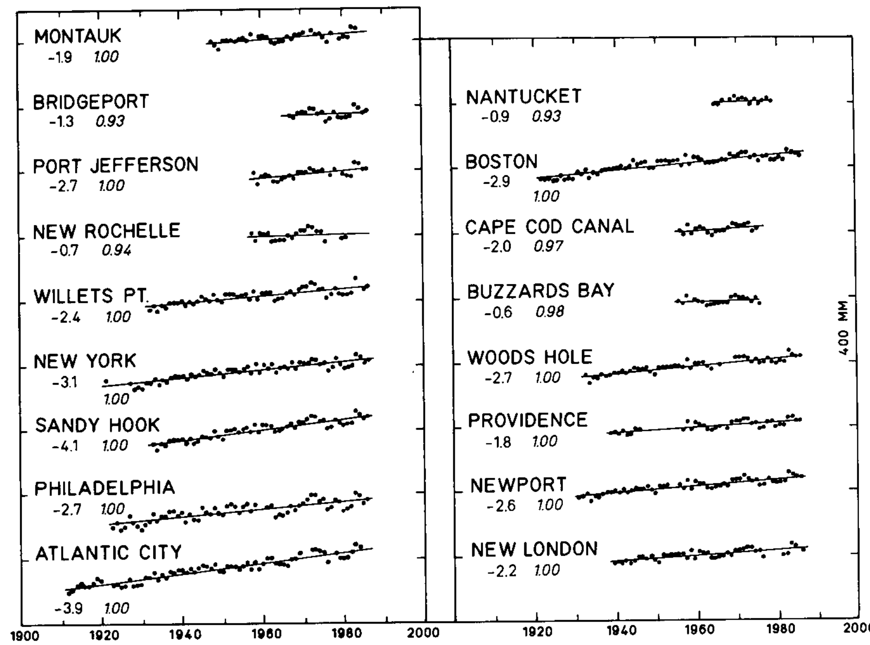
The subsidence of the watershed of Buzzards Bay (and the region) is due to the after effects of the same ice sheets that led to its formation. As the Laurentide Ice Sheet, with its Buzzards Bay, Cape Cod Bay, and South Channel lobes, formed and expanded, it imposed an overburden on the earth's surface. This overburden resulted in a "sinking" of the land surface under the load and a rise around the margin of the ice sheet. The rise around the margin is called the peripheral bulge, which during the last ice age extended along much of the Atlantic coast with a high centered near Cape Hatteras (cf. Emery and Aubrey 1991). As the ice sheet melted, the weight was released and the land surface rebounded with a concomitant subsidence of the peripheral bulge. The initial rise in sea level into Buzzards Bay resulted from this subsidence and the return to the oceans of the vast amount of water that had been held in the ice sheets.

The fraction of relative sea-level rise resulting from eustatic (oceanic) sea-level rise is of present concern in that the rate of rise may be accelerating because of climate change. Predictions of eustatic sea-level rise over the next century are driven predominately by attempts to assess the extent of thermal expansion of ocean water and the volume of "new" water entering from the current glacial stocks, both factors related to hypothesized global warming trends.

Because the Buzzards Bay lobe extended south of the bay and a terminal moraine extended south to Long Island, recent sea-level rise in Buzzards Bay can be evaluated within this regional context. The contours generated from many spatially separated tide gauges measuring relative sea level increase tend to parallel the historic margin of the Laurentide Ice Sheet with Buzzards Bay at the peripheral bulge (Fig. 6.5). Recent rates of relative sea-level rise in southeastern New England and Buzzards Bay have been determined from tide gauge records, generally from within the past 70 years (Fig. 6.5 A and B). Although there is significant year-to-year variation in the records, all of the tide gauges in the region indicate increasing relative sea levels, although the long-term rates vary. In the Buzzards Bay watershed over the past century, relative sea level has been rising at about 0.24 m/100 years (2 mm/year) with about 0.09 m from global sea level change and 0.15 m from sinking of the land (Emery and Aubrey 1991). Whatever the cause of the rise and regardless of the debate over acceleration in the current eustatic component, the relative sea level will continue to rise at least at current rates, and the modification this produces to Buzzards Bay shores will continue far into the future.

Effects on Upland Area. As the sea rises in this region, it covers (floods) the historic upland surface. The degree of encroachment on the land is directly related to the amount of land at each new flooding elevation and to the erosional retreat of the upland face, headlands, and scarps. However, in Buzzards Bay most of the upland is protected from ocean waves, and the flooding over or passive retreat of the upland edge is the major contributor to land loss (Geise 1989). It is not possible, at present, to ascertain the incremental retreat at each point along the Buzzards Bay coastline. However, because sea level rises over long periods and the landscape in most areas decreases in elevation, it is possible to predict the long-term rate of passive retreat of the upland edge from hypsometric curves of the upland topography. An upland hypsometric curve is the cumulative percent of the area of interest (e.g., a town) below each measured elevation relative to current sea level (Fig. 6.6). The curve indicates the area of land lost as the rising sea floods the lower elevations. When used to determine rates of loss over large areas and long periods (25-100 years) in watersheds like Buzzards Bay, the technique has useful application, especially as a management and educational tool.

Hypsometric curves for representing the extremes found in the Buzzards Bay watershed, New Bedford (western shore), and Wareham (head of the bay) demonstrate the low relief of the land surface. The elevational distribution of each town also indicates its different susceptibility to upland loss in



Top: At the left of each record is the name of the station, the mean annual change of relative land level in mm/year (regular numbers) and the t-confidence of the regression line (italic numbers).

Bottom: A. Positions of tide-gauge stations from above. The edge of the latest Wisconsinan ice sheet at its maximum extent (about 16,000 years B.P.) lay along the offshore islands. B. Mean annual change of relative land level based on linear regression analysis of full records from tide gauges. Contours show areal distribution of rates in mm/year.

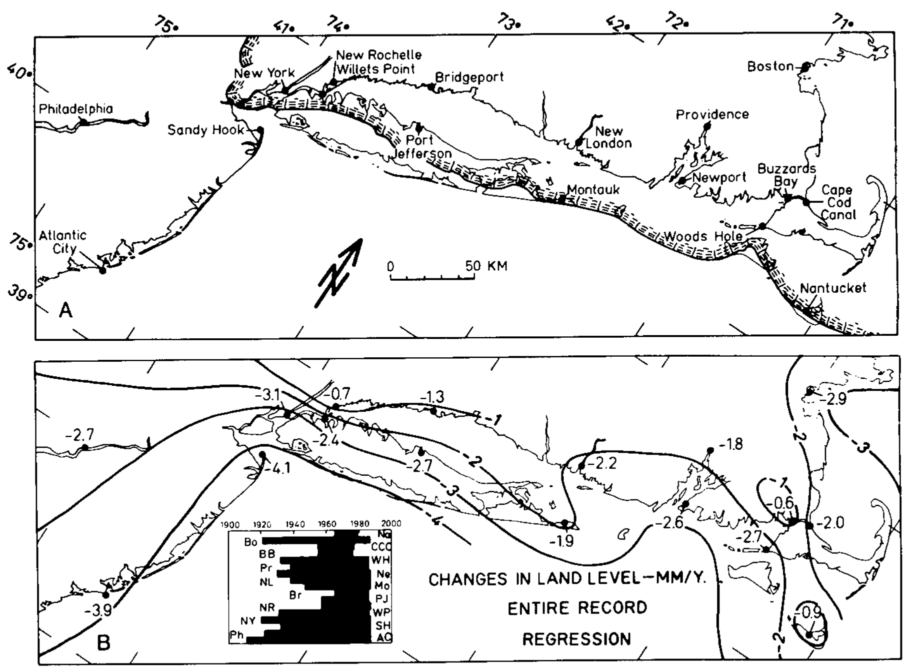


Fig. 6.5. Mean annual and changes in relative land levels at tide-gauge stations in Long Island Sound and vicinity. From Emery and Aubrey (1991).

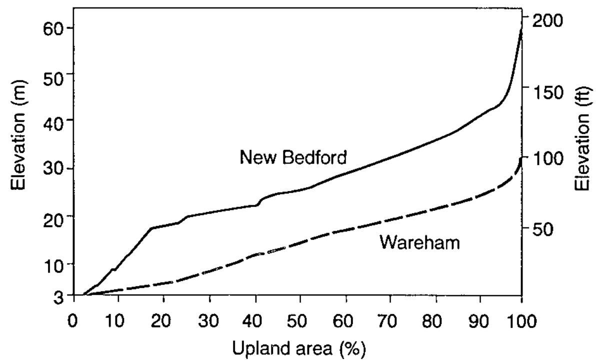


Fig. 6.6. Hypsometric curves for the upland areas of the Buzzards Bay towns of New Bedford and Wareham. Adapted from Giese (1989).

the face of a rising bay. Almost half (47 km^2) of the upland surface of Wareham is less than 12 m above sea level, while only 15% (7 km^2) is this low for New Bedford (Fig. 6.6).

It is possible to determine bay-wide land loss using hypsometric curves for each coastal town in the watershed and the predicted rate of sea-level rise. The major weakness in this method is not the hypsometric approach but the prediction of future water levels (Fig. 6.7). As stated above, at present the eustatic component is about one-third of the total rise (0.09 m out of 0.24 m/100 years).

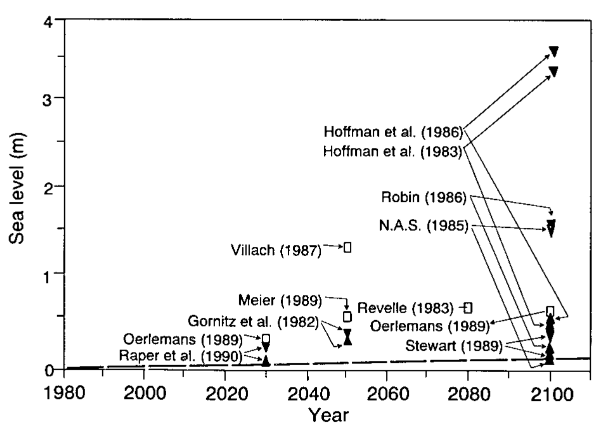


Fig. 6.7. Future sea level projections by various authors. Hollow rectangles represent spot estimates, solid triangles mark extreme ends of range estimates. Dashed line is the trend if present "assumed" rate of eustatic sea-level rise continues unchanged. Adapted from Emery and Aubrey (1991).

However, some forecasts of global climate change suggest that this rate may increase several fold over the next 100 years. As no accurate value is available, predictions generally use a range of future rise rates encompassing the various models available. Giese and Aubrey (1987) and Giese (1989), using the large range of eustatic rise rates by Hoffman et al. (1986) and local rates of subsidence (Braatz and Aubrey 1987), estimated land loss from hypsometric curves for each coastal town in the Buzzards Bay watershed (Table 6.3). The increasing difference in the hectarage from the high versus low estimates of sea-level rise through time results mainly from the increasing uncertainty in long-term predictions. In the near term (50 years), however, the differences between estimates are less than two-fold and with significant loss of upland, about 1,000 ha, or 1% of the total land mass.

In addition to the direct flooding of upland, secondary effects such as increased additional flooding during storms, coastal erosion, saltwater intrusion, and raising of the groundwater table will occur. The impacts on coastal infrastructure will most certainly be disproportionate to the percent of hectarage lost due to the concentration of the population and development in the low-lying areas directly adjacent to the coast. As stated above, the encroachment of the sea on upland is occurring region wide (Giese and Aubrey 1987; Fig. 6.8) and indeed throughout most of the world.

Effects on Saltwater Wetlands. In contrast to effects of relative sea level on uplands, salt marsh area is not necessarily impacted, and in fact, sea-level rise is involved in the maintenance of healthy tidal wetland functioning. The vegetated regions of salt marshes can be divided functionally into high versus low marsh, where high marsh is only intermittently flooded and dominated by *Spartina patens, Distichlis spicata*, and *Juncus* spp., and low marsh maintains a more intimate contact with estuarine waters, being routinely flooded and vegetated by *Spartina alterniflora* (Redfield 1972; 1967; Nixon 1982; Teal 1986; cf. Chapter 4).

The distribution of plant communities in tidal wetlands is predominately related to the tidal flooding

Table 6.3. Projected losses of upland acreage in Buzzards Bay coastal towns. Based upon low and high estimates of sea-level rise (SLR). Adapted from Giese 1990, and Giese and Aubrey 1987.

Coastal town	Town land area (ha x 1,000)	SLR	Area of land submerged (ha) 2,025	2,050	2,075	2,100
Westport	13.7	Low	27	48	77	115
		High	43	100	308	577
Dartmouth	15.8	Low	49	87	141	210
		High	79	183	563	1,056
New Bedford	4.9	Low	14	25	41	62
		High	23	53	165	309
Acushnet	4.7	Low	5	9	15	23
		High	8	19	60	113
Fairhaven	3.2	Low	32	57	93	138
		High	52	120	371	696
Mattapoisett	4.5	Low	17	29	47	71
		High	27	62	190	355
Marion	3.7	Low	51	91	146	218
		High	82	190	585	1,097
Wareham	9.5	Low	112	200	323	481
		High	180	418	1,291	2,421
Bourne	10.6	Low	36	65	105	157
		High	59	136	420	788
Falmouth	11.5	Low	91	162	263	391
		High	147	340	1,050	1,968
Gosnold		Low	14	25	40	59
		High	22	52	159	299
Totals		Low	448	798	1,291	1,925
		High	722	1,673	5,162	9,679
Estimated SLR		Low (m)	0.18	0.34	0.52	0.76
Total from 1980		High (m)	0.30	0.67	2.07	3.87

frequency and duration. Along the eastern coast of North America, low marsh areas tend to be colonized by *S. alterniflora,* as is the case for the Buzzards Bay estuary. In fact, the region of the tidal range (mean high - mean low water) where *S. alterniflora* will persist appears to be constrained to a zone of about two-thirds of the tide range (although subject to local variation), which is also true for Cape Cod marshes (Fig. 6.9). The difficulty in maintaining low and high marsh within the appropriate flooding range stems from the need to balance the accretion of the marsh surface with the rate of sea-level rise. In the southeastern Massachusetts marshes, accretion is predominately from the accumulation of decomposed roots and rhizomes of the wetland plants with little inorganic accumulation (Redfield 1972; Howes et al. 1985; Orson and Howes 1992). This contrasts with wetlands in areas receiving significant sediment loading from rivers (e.g., Mississippi Delta) where inorganic accumulation predominates (Baumann et al. 1984; Salinas et al. 1986).

While accretion rates vary within each marsh, the marsh flats colonized by *S. alterniflora* appear to be accreting at the same rate as relative sea level is rising. This is the case for two marsh systems proximate to Buzzards Bay, Barnstable (Redfield 1972) and Waquoit (Orson and Howes 1992). The continual rise in relative sea level accommodates wetland elevation increase without significantly

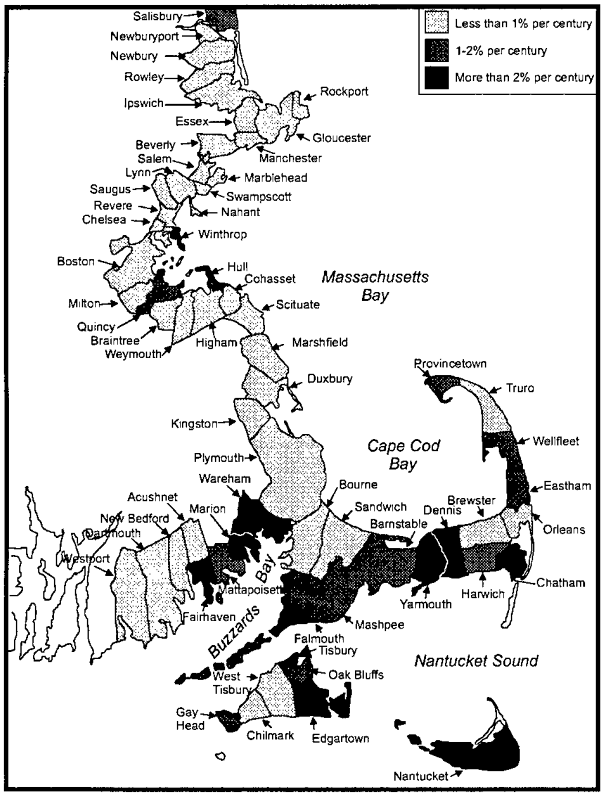


Fig. 6.8. Upland retreat rates for Massachusetts coastal communities, expressed as the percentage of total upland lost per century at the present rate of relative sea-level rise. Note several barrier beaches and sand spits are not shaded and are not included in the calculations of upland loss for their respective towns. From Giese and Aubrey (1987).

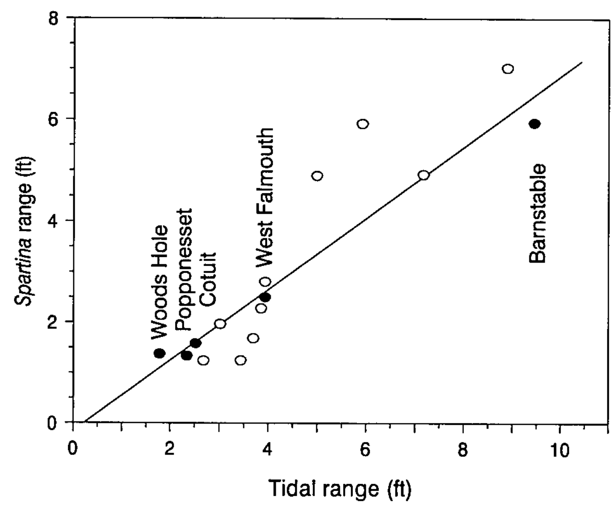


Fig. 6.9. Vertical range of *Spartina alterniflora* in relation to the range of the tide. Open circles: positions between Massachusetts and Florida; solid circles: positions on Cape Cod. The slope of the line is 0.7. From Redfield (1972).

altering the flooding frequency and duration of the wetland plant communities. This necessitates a balance between the rate of sea-level rise and sediment accretion, however. At present rates of sea-level rise, Buzzard Bay wetlands appear to be able to maintain their elevation, and marsh drowning and the conversion of vegetated marsh to open water is not occurring. Given that almost all of the vertical accretion is self-generated (organic matter produced by the plants) rather than trapped imported inorganic matter, however, it is likely that at the highest rates of relative sea-level rise some of the wetland area will be converted to open water. This conversion will have an associated loss of wetland functions within the estuarine system, such as nutrient transformations, spawning and nursery grounds for fish and shellfish, etc. The rate of sea-level rise that results in the conversion of wetlands to open water is currently the subject of intense study.

Even if the wetlands can "keep up," changes will occur, and in the Buzzards Bay system the salt marsh area is likely to diminish. As stated, as relative sea-level rises, the upland retreats. Because wetlands are composed of relatively unconsolidated sediments, they persist only in lower wave energy environments, and therefore they will be eroded back with the land margin on an open shore. The more general case for Buzzards Bay is the development of salt marsh behind a barrier dune complex (Fig. 6.10). As sea level rises, storms occasionally erode the dune barrier and wash the sand back onto the marsh in a process called overwash (Fig. 6.11A). With successive overwash events and continually rising sea level, the dune complex is reestablished inland of the initial location over some of the present marsh, and old marsh surface can be exposed on the new shore (Figs. 6.10 and 6.11B) where it is quickly eroded by the direct wave action from Buzzards Bay. With the now-higher sea level, however,

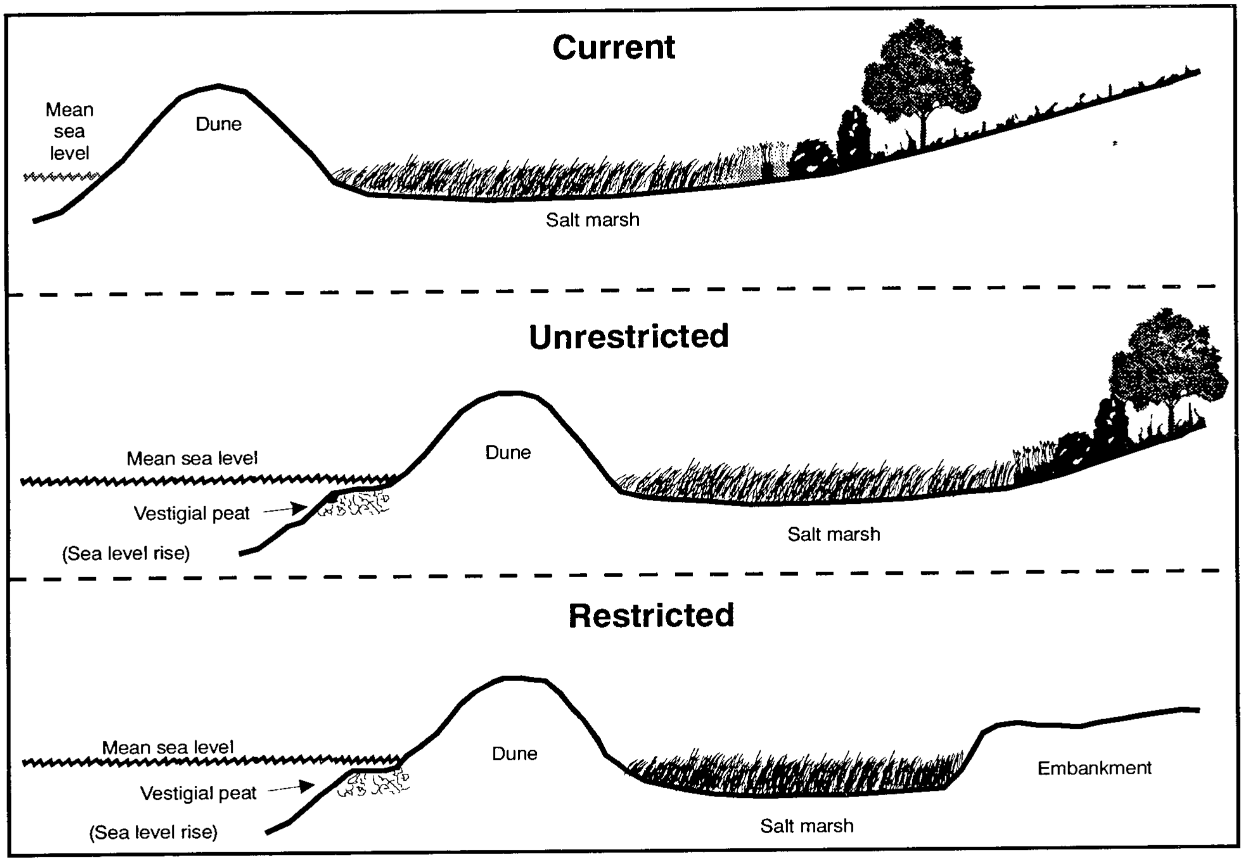


Fig. 6.10. Response of the current barrier dune marsh system to rising sea level under unrestricted and restricted conditions at the marsh-upland interface.

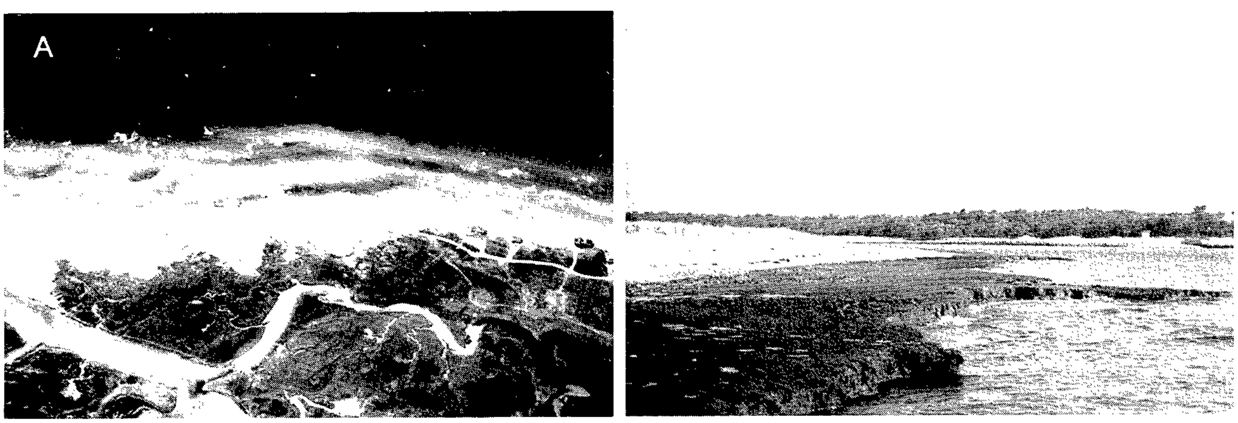


Fig. 6.11. A. Aerial view of dune overwash. Storms carry the barrier dune back over the marsh where they eventually reestablish. B. Vestigial peat. Remains of old salt marsh protruding seaward after protective barrier dune migrated landward over the marsh. Photos by D. Goehringer.

tidal flooding begins to flood upland farther inland. The result is that marsh species at the former marsh-upland boundary can now colonize over previous upland communities. The total effect is that the entire wetland system migrates inland (Fig. 6.10), and although each marsh varies, the net effect does not necessitate significant wetland loss; in fact, wetland expansion could occur. The most likely result

for Buzzards Bay, however, will be the loss of wetland hectares. Much of the current upland/wetland border is currently or likely to be armored or graded to protect inland areas from flooding by coastal storms.

The result of these alterations to the upland-marsh boundary is that as the bay edge of the marsh migrates inland, the marshes will compress into the upland embankments decreasing their areal extent (Fig. 6.10). This potential mechanism for loss of wetlands is a management issue that increases in importance as coastal development continues in the face of an increasing rate of relative sea-level rise. Ecological impacts of wetland loss extend out into the bay and are possibly multiplied in that the nutrient-buffering capacity provided by wetlands may be decreasing just as the loading from the watershed is increasing.

Marsh Dieback. Alteration of the flooding frequency and duration of wetlands, as a result of changing relative sea level or in response to human alteration of the hydrodynamic regime, can lead to rapid, local large-scale declines of salt marsh plant communities through a process called "dieback." This response is similar to the initial stages of wetland conversion to open water such as what occurs when sea level is rising faster than the marsh surface can accrete. Salt marsh dieback is a poorly understood phenomenon where large stands of tidal wetland plants simply die. Major dieback events have occurred in North Carolina, Louisiana, parts of the mid-Atlantic coast, and Great Britain (Goodman and Williams 1961; Smith 1970; Sears and Parker 1981). The first documented case of marsh dieback in New England occurred at Nonquitt Marsh, South Dartmouth, beginning in the mid-1970's. By September 1980 over 60% of the formerly healthy stands of *Spartina alterniflora* had become denuded. The marsh lies along the southwestern shore of Buzzards Bay and is bordered on three sides by hardwood and pine upland and by a barrier beach and road running parallel to the shore. Tidal exchange with the bay is through a culvert running under the road, which operated for over four decades prior to the dieback event. Investigations conducted into the potential cause of this dieback (Sears and Parker 1981) ruled out domestic and chemical pollutants.

Although there are many hypothetical causes for various dieback events, the one at Nonquitt Marsh is thought to be due to restriction of tidal exchange. The adverse impact of impeded circulation within this type of system is extended soil waterlogging, which results in oxygen deficiency that can alter the physiology and growth of *Spartina* (Mendelssohn and Seneca 1980; Howes et al. 1986). Between 60% and 80% of the tidal volume remains within Nonquitt Marsh between tidal cycles, as compared to other healthy systems like Barnstable Marsh, Massachusetts, where only 10% of the volume remains in the confines of the marsh system at low tide (Redfield 1972). In Nonquitt, the marsh was apparently able to tolerate restricted circulation for several decades until storms appear to have caused excessive clogging of the culvert, triggering the dieback event.

Although dieback occurs rapidly, recovery occurs over longer periods, even after adequate tidal exchange is restored. In Nonquitt, initial regrowth along the denuded edges began immediately, with naturally invading plants having somewhat more success in colonization than transplants. Four years later most of the barren areas remained wet or waterlogged with little new growth, except for sparse occurrences of rapidly colonizing *Salicornia* species. The remaining large denuded areas are most likely due to the highly reducing conditions resulting from extended soil waterlogging, as well as salinity elevation in shallow pools and sediments on the marsh surface resulting from evaporative losses. Concentrations of up to 55 ppt chloride were found in the top 2 cm of sediment in denuded areas (threefold higher than Buzzards Bay waters); however, tidal water salinities did not appear significantly elevated (D. Goehringer, unpublished data). It appears that as plants recolonize the edges of this marsh, sediment characteristics become more favorable for growth with increased oxidation of the sediments in the presence of plants (Howes et al. 1986). Without restriction to circulation, much of the wetland probably will recover to predieoff conditions. On the other hand, the settling of peat and

erosion of the marsh surface in many areas has created shallow depressions that retain standing water and are likely to restrict regrowth for many more years.

6.2.2. Storms

In contrast to the gradual effects of continuous relative sea-level rise, storms are infrequent and sometimes cause major physical and biological changes in a matter of moments. The reason for the temporal disparity is that sea-level rise in Buzzards Bay is caused by geologic processes of land subsidence and changes in global sea level, while the effects of storms are the result of rapidly changing atmospheric and tidal phenomena that exist for hours to days. The gradual and infrequent processes that drive coastal changes both produce management problems because the effects are not readily observable on an annual scale.

Although storm occurrence is irregular and unpredictable from year to year, over longer periods there is a probability of a major storm every 1-2 years and smaller storms at a much higher frequency (Fig. 6.12; Aubrey and Speer 1984). Storm occurrence is seasonal, composed of the Atlantic tropical storms in late summer and fall and northeast storms of winter. In all, there have been at least 160 gales (wind greater than 15 m/s) in the Atlantic coastal region of Cape Cod from 1870 to 1975 (cf. Aubrey and Speer 1984). It is difficult to determine the precise number of storms per year over past centuries because the early records tend to include only major storms. The apparent recent increase in storm frequency since 1948 demonstrates

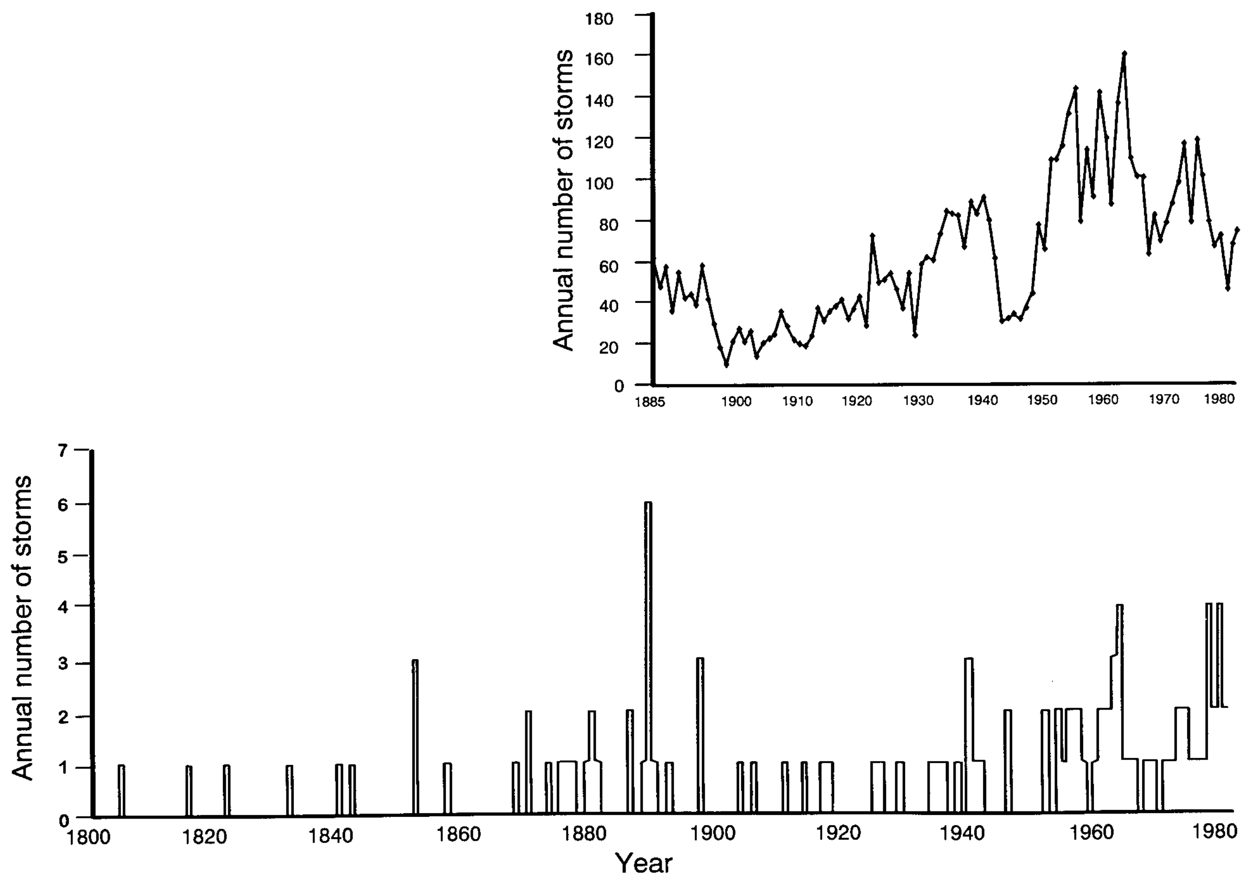


Fig. 6.12. Cyclone activity affecting the area of Cape Cod (60° W to 70° W, 37.5° N to 42.5° N) from 1885 to 1982. Storm count is indicative of storm number and duration, not individual events. The data addresses long term trends in relative storm occurrence. From Aubrey and Speer (1984).

the high frequency of major storms in the region. The magnitude of the effect of storms on the Buzzards Bay system is determined by a variety of factors, most importantly wind speed and direction, tide stage, rainfall, and season.

Storms, both hurricanes and "nor'easters," tend to approach Buzzards Bay from the south. Wind speed and direction are determined, in part, by the track of the storm center as it passes the bay moving northward. Storms in the northern hemisphere rotate in the counter-clockwise direction (Fig. 6.13). The effect of this rotation in a storm moving northward is that the wind speed of its eastern portion is effectively increased by the storm's advance while the winds of the storm's western portion have a lower ground speed. The enhanced wind effect on the eastern side of the storm has termed that side of the cyclone the "dangerous semi-circle" (Oldale 1992). The effect on Buzzards Bay is that storms with centers passing to the west tend to produce the most coastal erosion and flooding.

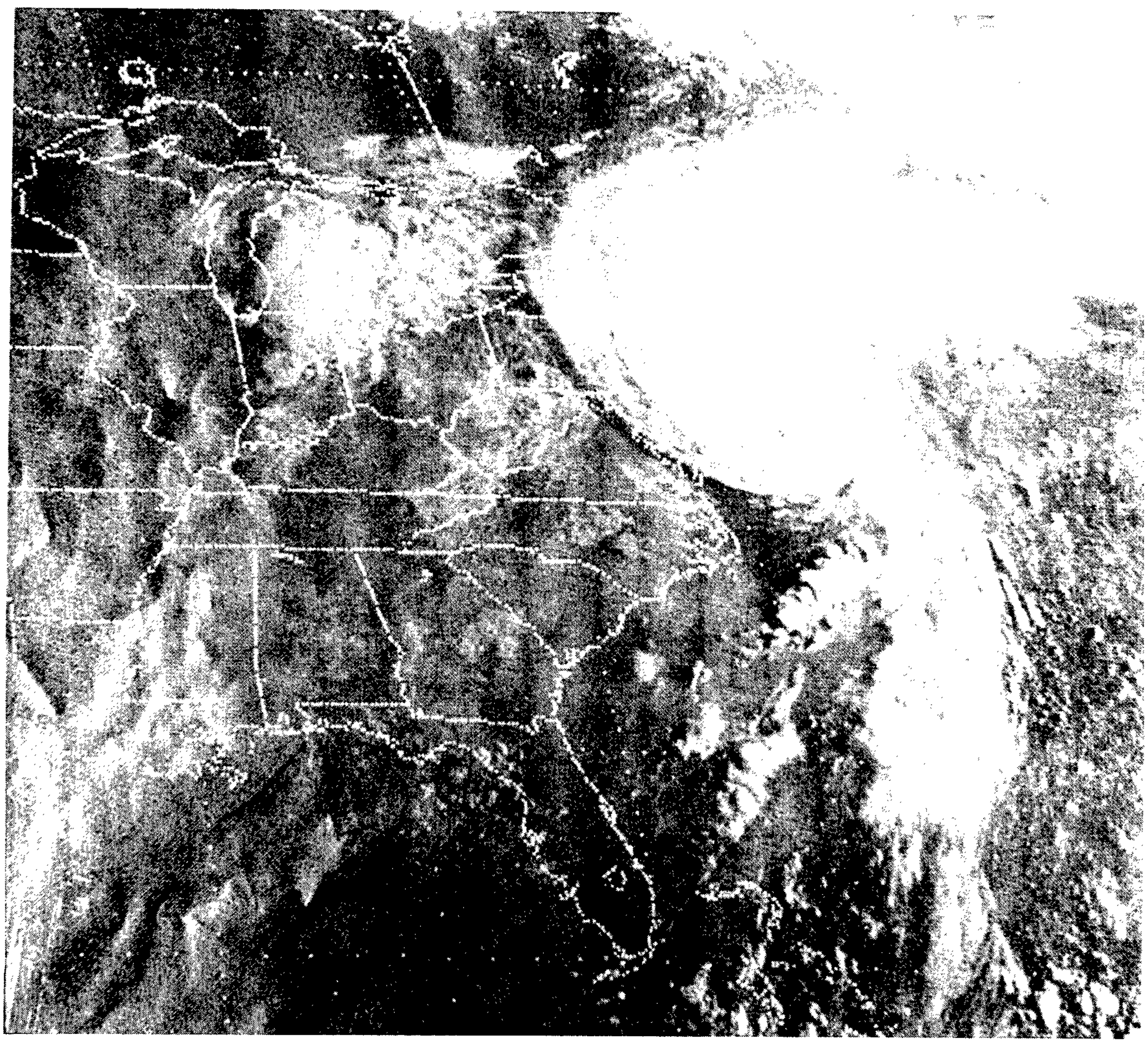


Fig. 6.13. NOAA satellite photograph of Hurricane Bob, 19 August 1991, at 1131 h. The eye of the hurricane is south of Buzzards Bay, off the coast of New Jersey. The counter-clockwise rotation of the storm can be clearly seen as the storm moves northward. From Potter (1991).

The effect of the wind has greater consequences than direct damage and producing larger waves; in the Buzzards Bay system winds can also have a major effect on storm surge. Surge is the increase in bay water levels associated with meteorologic as opposed to lunar (tidal) events. Buzzards Bay is a funnel-shaped estuary with the mouth facing to the south-southwest, a situation enhancing the build-up of wind-driven water (surge) most dramatically at the head of the bay as a storm moves northward (the normal path) and passes to the west. Surge is also created by the low barometric pressures of storm systems, especially hurricanes. The waves built up by storm winds ride on top of the surge, allowing them to strike the coast with greater force and penetrate farther inland.

Given the positioning and structure of Buzzards Bay, the ingredients for a maximum strength coastal storm are a major storm (e.g., hurricane) passing near the west of the bay, maximizing winds via the dangerous semicircle effect, and maximum water levels from surge coinciding with the lunar high tide. These were just the conditions for the largest storm to hit the bay in recorded history, the "Great Long Island-New England Hurricane of September 21, 1938" (cf. Potter and Steward 1991). The forward motion of the hurricane was 97-113 km/h with sustained winds of 121-145 km/h and gusts to 161 km/h when it reached Buzzards Bay. In the upper bay, the storm surge raised levels 4 m above the coincident high tide, with waters 4.9 and 5.8 m above mean low water in the bay's mid and head regions, respectively. The combined high waters and 2.4 m wind-driven waves tossed rocks through windows 8.8 m above mean low water at a site near the entrance to the Cape Cod Canal (Oldale 1992). The 1938 hurricane was extreme but not unique. In 1954 Hurricane Carol followed the 1938 track and produced an even higher surge (4.9 m) because the eye passed closer to the bay. It is clear that other similar storms have taken place and will continue to occur.

Storm effects on the Buzzards Bay system are related to sea-level rise although they differ in several aspects. One way to envision the relationship is that storm effects can be increased incrementally; i.e., wave height on a surge on a high tide on a rising bay level. The impact of sea-level rise, on the other hand, is more constant and can be predicted with some confidence. An important difference is that while flooding by bay incursions during storms may produce "short-term" effects, an area flooded due to relative sea-level rise persists. Both of these short- and long-term processes result in coastal erosion and the retreat of the shoreline.

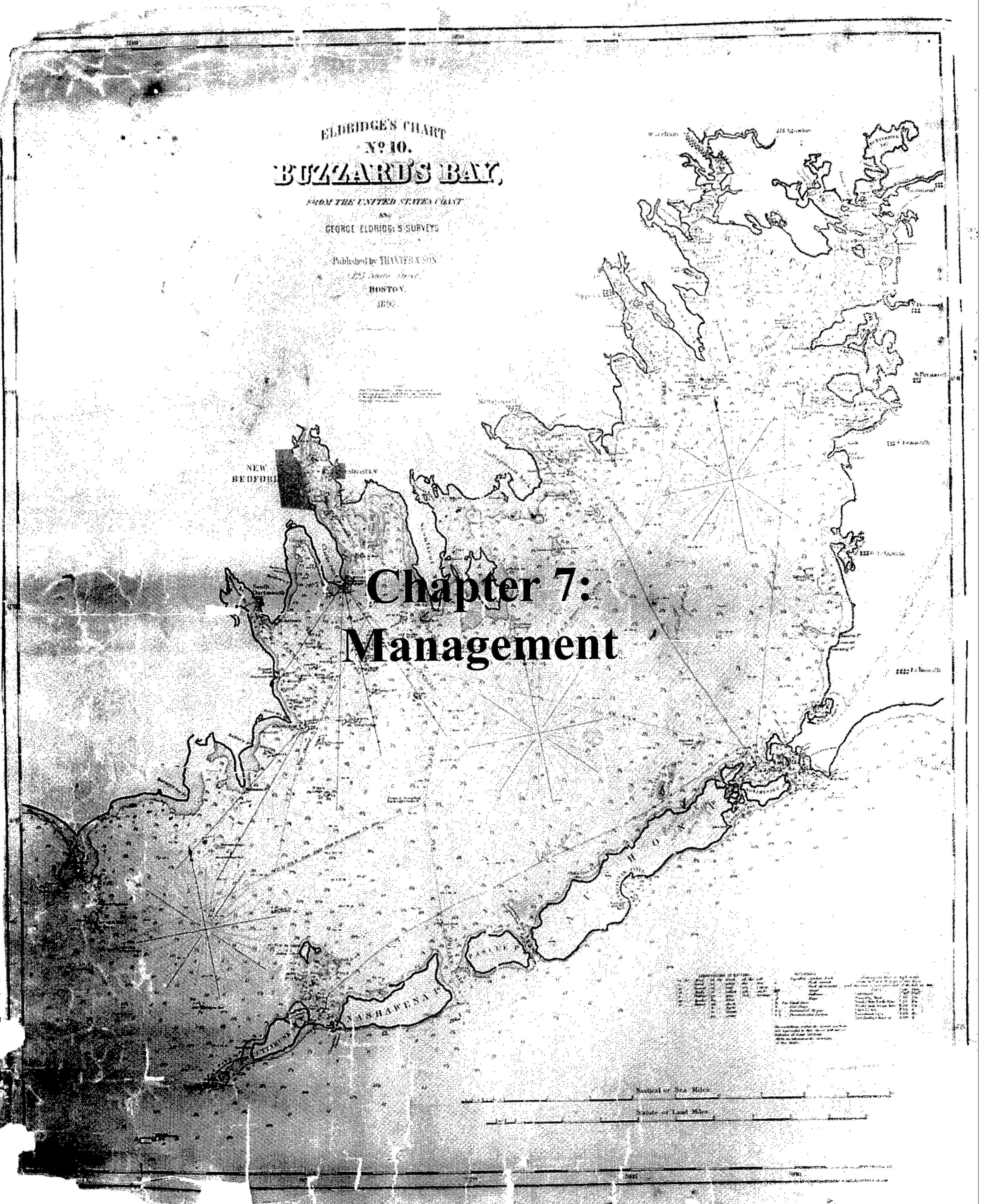
Storms do have some unique physical and ecological effects on the bay system. Overwash of sand from barrier dunes onto salt marshes (Fig. 6.11A) not only restructures the dune systems and sometimes tidal inlet dynamics, but also can produce changes in plant communities. If overwash deposits cover salt marsh to a level above all but the highest tides, they will not be recolonized by the marsh grasses or by dune plants but sometimes will persist for many years with a cover of opportunistic colonizers (e.g., *Salicornia*). Storms can affect inland plant communities as well, not only through the obvious effects of uprooting trees but also often through greater effects of desiccation and salt sprays as almost all inland plants are not salt tolerant. These latter processes were responsible for major impacts to the terrestrial ecosystems within the Buzzards Bay watershed during the passage of Hurricane Bob, 19 August 1991. The eastern shore of the bay received almost no rain during the hurricane, but instead a spray of salt water was delivered kilometers inland. The result was that many deciduous trees browned and lost their leaves, and a few died. However, among the affected conifers, particularly the relatively salt-sensitive white pine trees, a mortality of 50% was predicted (Potter 1991). The effects of salt spray are compounded by the simultaneous high winds, which increase the rate of evaporation from the leaves and hence enhance their desiccation.

Storms that deposit significant fresh water can also have important ecological impacts, primarily on aquatic systems. The increased freshwater flow into coastal salt ponds and embayments carries with it sediments and nutrients and frequently results in a temporary stratification of water columns.

Stratification effectively isolates the lower waters from the atmosphere, which in nutrient-rich systems with high rates of oxygen consumption can result in depletion of dissolved oxygen (Costa et al. 1992; Taylor and Howes 1994). The indirect effect of stratification is a significant impact to the animal and plant communities of the receiving water body.

Building seawalls and armoring the coast in the face of a continually rising bay and periodic storm events may provide a temporary local solution to land loss by erosion and flooding. Over the long term, however, the Buzzards Bay watershed will diminish in size, and the salt marshes, barrier dunes, and beaches will continue the retreat that they began shortly after Buzzards Bay first became an estuary.

Chapter 7: Management



For U.S. mid and North Atlantic coastal estuaries, Buzzards Bay stands out as a relatively clean and healthy ecosystem with abundant natural resources and high aesthetic, commercial, and recreational value. As more and more coastal embayments succumb to water quality degradation resulting from ever-increasing development pressures, the desirability of Buzzards Bay unavoidably increases and threatens the health of this system. The effect of increased coastal development is evidenced by the parallel rise in the number of shellfish bed closures (Fig. 6.1) and increasing eutrophication in the bay's smaller harbors and embayments. Without proper environmental management strategies, the desirability of Buzzards Bay could, in effect, cause its decline as well.

7.1. Toxic Pollutants

Most of the concern over toxic pollutants in Buzzards Bay centers on the PCB and heavy metal contamination of New Bedford Harbor (see Chapter 6). The concentrations of PCB's and heavy metals in harbor sediments are so high in the inner reaches of this harbor (up to 30,000 ppm) that it was designated by the EPA in 1982 as one of the Nation's worst hazardous waste sites, resulting in 7,285 ha of the harbor region being declared the Nation's first marine Superfund site. Subsequent study has identified 399 ha of the Inner New Bedford Harbor region as the focus area. Concern over public and environmental health surrounding this toxic waste site has resulted in numerous studies to quantify existing conditions as well as to define potential remediative measures. The feasibility studies for remediation have focused on several evaluation criteria: overall protection of public health and the environment; long-term effectiveness; reduction in the mobility, toxicity, or volume of contaminants through treatment; feasibility (logistic and economic); and acceptability to both the State of Massachusetts and the New Bedford community. Several alternatives have been presented, including capping, removal via dredging and disposal, and removal and treatment by various methods, that would result in various levels of contaminant reduction. "No action" is also being considered an alternative as serious concern surrounds the potential deleterious impacts of resuspending, hence reintroducing, deeper sediment-bound contaminants to the active biotic zone. As of 1995, the alternatives were still under review, and new information from research and feasibility studies continues to enter the process. It is clear that it will be some time before PCB contamination no longer presents a hazard to the ecological health of New Bedford and Buzzards Bay.

After the discovery of significant PCB contamination in New Bedford Harbor, one of the first major regulatory actions was aimed primarily toward protecting the public health and was implemented in 1979. A series of restrictions was imposed moving from the area of greatest contamination toward the better flushed regions of the outer harbor and out to where the harbor becomes part of Buzzards Bay proper. The regulations range from restricting the taking of lobsters, fish, and shellfish from inner harbor regions identified as highly contaminated, to limiting take of just bottom-feeding fish and lobsters with distance away from the inner harbor region, and finally to restricting only the taking of lobsters farther out toward the open waters of Buzzards Bay. The closures related to this contamination have resulted in annual losses of over $250,000 to the lobster fishery alone (Ciavattieri and Stockinger 1988). Many of the closures related to toxic contamination, however, are also areas that would be closed to fishing as a result of intense harbor activities or sewage outfall.

Certain toxic compounds like PCB's are resistant to both chemical and biological degradation and persist in the environment for long periods, all the while exerting acute and chronic impacts, especially on benthic animals. Many metals and PCB's are incorporated into bottom sediments; burial is the major natural removal mechanism for these compounds within the bay. Within New Bedford Harbor, rates of sediment accumulation reach 3 mm/year (Howes and Taylor 1990), which over time will isolate incorporated compounds from the active biotic zone in the water column and surficial

sediments. Compounds may, however, reenter the system directly by resuspension or indirectly by ingestion by benthic communities with possible transfer up the food chain. Because PCB's have been found in birds like the ring-billed gull and in white-footed mice (*Peromyscus* sp.), it is clear that food chain transfer of this contaminant is occurring, possibly resulting in biomagnification of the toxin with increased predator size. Of additional concern are potential alterations to the benthic communities with shifts to more pollution-tolerant species, which may in turn modify the prey resource for other species, especially bottom-feeding fish. Unfortunately, the cooccurrence of many pollutants within the contaminated areas makes it impossible to accurately identify this effect. The good news is that PCB, organic toxin, and heavy metal inputs to the bay through water flows can be controlled by environmental management practices because they tend to be point sources and can be adjusted before discharge. The major problem in this area, at present, is the remediation of previously discharged compounds.

The New Bedford/Fairhaven area discharges almost all of the toxic pollutants and heavy metals and more than half of the sewage inputs to the bay (cf. Chapter 6). This historic "concentration of impacts" has led to an isolation of ecological degradation in the nearshore zone (Howes and Taylor 1990; Costa et al. 1992) of one of the bay's 27 embayments.

Other sources of toxic pollutants to Buzzards Bay tend to have more widespread inputs and are therefore more difficult to manage; however, most of these inputs are small, such as road runoff or the leakage of nonvolatile and volatile compounds from recreational outboard motors (the notable exception is infrequent but dramatic oil spills). Increased effectiveness of quick response to large and small oil spills and improved cleanup techniques designed to minimize impacts are now being supported by spill prevention methodologies within the bay's harbors. As with all human introduced compounds, the focus of management on prevention of discharge rather than remediation is becoming the standard. The impacts of recent Buzzards Bay spills remain fresh in the memory of many and provide a base for management. At present, however, the inputs of hydrocarbons in sewage effluent, industrial discharges, and stormwater runoff may actually equal the inputs from accidental spills (Farrington and Capuzzo 1990). Efforts to increase awareness of citizens of their role in oil inputs and to develop regulations aimed at minimizing inputs from these sources are underway for Buzzards Bay by local communities as well as regionally through the bay-wide Buzzards Bay Project and Coalition for Buzzards Bay.

7.2. Coliform Contamination and Shellfish Closures

One of the primary consequences of increased pollution in Buzzards Bay is reflected by the significant increases in shellfish bed closures in recent years (Fig. 6.1). The parallel between the increase in these closures and increasing development in the bay watershed has led many to conclude that faulty septic systems are the primary culprit. Evidence is increasing, however, that although septic systems are a potential cause, other sources may be more important (Heufelder 1988; P. Weiskel, U.S. Geological Survey, Marlborough, Massachusetts, personal communication). Although measurements of fecal coliform bacteria are not accurate indicators of sewage contamination (or for that matter nutrient pollution) because of the various sources of bacteria, the trend in shellfish closures due to coliform contamination does reflect the increased population growth along the bay. In 1970, an average of 1,781 ha of shellfish beds were closed due to the presence of this enteric bacteria. In 1988, however, more than 4,452 ha were closed, about 10% of the total hectarage of open shellfish beds in Buzzards Bay (this figure temporarily surged to 7,689 ha after the New Bedford sewage treatment plant released 378,500 L of sewage into the bay). In 1989, roughly 5,059 ha were closed; in 1990 this number grew to nearly 5,666 ha, indicating a continual and steady increase in shellfish bed closures for Buzzards Bay waters. These closures are

grouped into two types: permanent and variable. Permanent closures are long-term restrictions with no immediate prospect for opening; variable closures are periodically closed and reopened. About 60% of the closures are permanent. Variable closures are generally related to weather (warmer temperatures increase bacterial activity and therefore often increase coliform populations) and sewage treatment facility malfunctions. In both cases, however, shellfish can be transferred to clean areas for growth and spawning purposes.

Fecal coliforms are the most common bacterial group used as indicators for potentially dangerous human viruses, which are the real public health concern involved in shellfish bed closures. Identification and quantification of coliform bacteria in coastal waters are relatively simple; this is not the case for viruses, however, and to date no routine methods are available for viral monitoring without great expense and specialized laboratories. Several problems surround the use of coliform bacteria as a monitoring tool. As intestinal bacteria, they are only indicators of pathogen inputs. This method gives no indication of toxic inputs or nutrient or oxygen conditions, which ultimately structure the ecological health of an environment and the viability of benthic communities and economic species of fish and shellfish. More importantly from a monitoring standpoint, the presence of coliform bacteria does not mean that viruses are present or even that human wastes are involved. Attempts to identify more specific bacterial indicators have as yet been unsuccessful, with no organism determined to be specific to human sources nor as easily measured as fecal coliforms and as cost effective as coliform monitoring. At least for the near future, regulators and managers have decided to remain conservative in protecting Buzzards Bay's residents and visitors, maintaining the use of fecal coliforms to identify potential threats to the public health.

High levels of coliform bacteria usually result in two regulatory actions: first, closure of shellfish beds to harvesting to minimize threats to public health through consumption; and second, closure of waters to swimming to minimize direct contact with contaminated waters. Shellfish depuration is occasionally undertaken when beds are closed, whereby the shellfish are removed from bacterially contaminated regions to clean areas and allowed to filter for a specified period (from days to weeks), subsequently ridding themselves of the temporary bacterial associates. After suitable testing, these shellfish are then evaluated for consumption.

There are several sources of pathogens and bacteria to Buzzards Bay, including sewer outfalls, poorly functioning on-site septic systems, stormwater runoff, wildlife, waterfowl, and domestic animals. Sewage treatment facilities utilizing outfalls are required to disinfect wastes before discharge; however, occasionally failures occur and wastes enter untreated. Bacteria from animal wastes can be introduced to Buzzards Bay waters both directly (primarily waterfowl) and indirectly through incorporation into stream and stormwater flows. Coliform contamination from storm runoff has been identified as the primary cause of shellfish closures in Massachusetts (Heufelder 1988; Weiskel et al. 1996), and apparently in Buzzards Bay as well. It appears that bacteria associated with animal wastes are washed from impermeable surfaces (roads), which frequently drain directly into the surface waters of an embayment. This helps to explain the relationship between increasing nonurban population (Fig. 6.1) and area of shellfish closures because the amount of impermeable land surface is related to development.

While potential coliform contamination from human wastes is also related to development, the only mechanism for transport involves breakout and surface flow from septic tanks since coliforms appear to migrate less than 2 m from residential subsurface disposal sites even if discharge is directly to the water table (Weiskel et al. 1996). In addition, coliform closures occur in areas already served with sewers as well as in areas of on-site disposal. Recent studies that compare the ratio of fecal coliform to fecal streptococci may be useful as fecal streptococci are often considered better indicators for human wastes. Case studies characterizing the sources of fecal coliform in storm water for the watershed of Bourne showed these ratios to be quite low, indicating only very limited instances of

contamination by human wastes (Gale Associates 1989 in SAIC 1991). In a similar study for Buttermilk Bay, most of the bacterial loading could be accounted for by dog waste (Heufelder 1988). Inputs from agricultural activities, notably dairy and beef industries as found within the Westport River watershed, may be locally important as an additional source of coliform bacteria, as increased levels of coliform have been observed in the Westport River. Without quantitative assessment of sources, management can focus on the wrong sources, but within the Buzzards Bay system determination of the importance of surface runoff has led to a priority to address surface-water discharges through rapid infiltration beds and is already showing positive results. New methodologies to deal with stormwater are being considered by several towns around Buzzards Bay. The town of Bourne recently installed an innovative filtration system that treats initial road runoff (about the first few centimenters of stormwater runoff, which contains most of the pollutants) before it reaches bay waters, the first in what is planned to be many stormwater remediation projects around the bay.

The difficulties in identification of specific sources of coliform bacteria have led researchers and regulators to also consider other potential direct discharges. Discharge of untreated boat waste, while not significant to nutrient loading baywide (cf. Chapter 6), is an important potential coliform and pathogen source. Although there has been an increase in the use of pump-out facilities for boat wastes, elevated levels of coliform bacteria are still evident in many marina areas. Recognition of the impact of direct discharges is leading to zero discharge regulations for Buzzards Bay; in 1992 the town of Wareham had its coastal waters designated as a Federal "no discharge area" by the EPA, the first such designation on the East Coast. This designation prohibits discharge of untreated and treated boat wastes and involves increasing boat pump-out facilities and providing an expanded boater education program.

Regardless of the source of bacterial contamination in Buzzards Bay waters, it is clear that there has been a significant increase in shellfish bed closures around the bay over the past few decades. These closures affect the recreational and commercial shellfisheries and restrict many water-based activities such as swimming and snorkeling. Increases in restriction of shellfishing and swimming with increased growth of the nonurban population within the watershed are resulting in increased attention to land use and management objectives to protect both the public health and shellfishing, one of the most important economic resources Buzzards Bay has to offer. Fortunately coliform contamination, while restricting resource use (swimming, fishing, etc.), does not seriously impact the ecosystem and animal species of the bay waters. The consequence is that finding and preventing future inputs will result in rapid "recovery" of the bay's resources.

7.3. Nutrient Loading

The primary sources of anthropogenic nitrogen inputs to Buzzards Bay are sewage treatment facilities, on-site septic treatment of waste, and fertilizers added to lawns, golf courses, and agricultural land (Fig. 6.4; Table 6.2). This nitrogen enters bay waters through direct discharge, groundwater transport, or stream flow (which often are supplied by groundwater). Overall, Buzzards Bay is well-flushed and at present maintains high levels of water quality. The smaller coves and embayments surrounding the bay, however, are the most sensitive to additional nutrient inputs due to their shallow nature and generally low-flushing characteristics (Table 1.3). These subsystems are of the greatest concern as they support most of the commercial and recreational shellfishing industries as well as much of the recreational activity around the bay, and most of the increasing population is settling in these areas (Fig. 1.5). New Bedford Harbor and Buttermilk Bay are examples of embayments that have experienced high nitrogen inputs and are therefore considered to be relatively impacted, New Bedford via its point source outfall and Buttermilk Bay via groundwater-transported inputs.

At present, only about 53% of the area in the Buzzards Bay watershed suitable for building has

been developed (Buzzards Bay Project 1990); this translates into a potential doubling of nutrients to the bay at maximum development. Because various embayments are showing the signs of incipient cultural eutrophication, the nearshore areas will suffer significant habitat degradation without some form of nitrogen management. Several mechanisms of nutrient management can be enacted with the aim of allowing watershed development to continue but in a fashion that mitigates potential damage to the estuarine system. The goals of managers, environmentalists, fishermen, and local citizens converge in that degradation of the embayments does not just affect ideological conservationism. Degradation also directly impacts jobs related to fisheries within the bay and on offshore species that rely on the bay and its marshes for portions of their life cycles, and the property values (e.g., capital investments) of all of the private citizens within the watershed. Therefore, it is in the personal and financial interest of the general population to support environmental management programs that protect resources or remediate degraded areas of the Buzzards Bay system. The increasing awareness of the need for resource management, particularly watershed nitrogen management, is being demonstrated by town governments, the growth of citizens' groups aimed at distributing information, and the active participation of individual citizen-based monitoring programs on a bay-wide scale (through the Buzzards Bay Project) and by individual towns (e.g., Falmouth).

Through individual efforts and as part of larger cooperative efforts of the Buzzards Bay Project and the Coalition for Buzzards Bay, towns within the Buzzards Bay watershed are now working toward more effective management strategies to minimize additional nitrogen inputs into the waters of the bay. Through these efforts, local by-laws and regional management plans for the bay that take into account the variety of land uses (Table 7.1), economic structure, and specific limitations (for instance, administrative or financial) of these different communities are being developed. An example of this is the cooperation between three towns, Bourne, Wareham, and Plymouth, to address the increasing eutrophication in Buttermilk Bay. Working with town officials, local and regional planners in the towns have adopted local zoning overlay districts, which rezone areas within the subwatershed in an attempt to minimize new sources of nitrogen to Buttermilk Bay.

With the goal of assessing water quality conditions baywide, the Buzzards Bay Project and the Coalition for Buzzards Bay, in cooperation with the Woods Hole Oceanographic Institution, initiated a citizen-based water quality monitoring program in 1992 aimed primarily toward monitoring nitrogen and oxygen conditions in the numerous nitrogen-sensitive coves and embayments around the bay. Not only does this project provide important information for the long-term assessment of coastal water quality in Buzzards Bay, but it also stimulates interest and education of the local citizens in protecting the environmental health of their nearshore coastal waters.

Technological advances may also increase the carrying capacity of the watershed. New systems are becoming available that remove nitrogen and phosphorus from wastewater. These systems can be added predischarge from outfalls or can be used on a small scale in the more sensitive areas of specific subwatersheds. Investigation is also continuing into the design of septic systems that are cost-effective and can remove nitrogen by stimulating microbial denitrification before discharge of the effluent to groundwater. However, one of the essential requirements to proper management is the determination of the assimilative capacity of individual embayments. While it may seem costly, this approach actually represents a fraction of the expenditure required in the prevention or remediation of nutrient loading. Given the expense of wastewater treatment systems it is inefficient to improve treatment over present systems in all areas within the bay system. The proper method is to determine the allowable nitrogen input and the locations where post-discharge magnification of the input is greatest and focus the efforts there. For instance, given the heavy metal, PCB, oil, and other inputs to New Bedford Outer Harbor and the relatively limited area

Table 7.1. Land use within the Buzzards Bay watershed. Adapted from Buzzards Bay Project (1990).

Land use type	Whole basin area (ha)	(%)	Whole basin 0.8 km buffer area (ha)	(%)
Developed				
Residential (all)	13,881	13.2	5,976	27.4
Commercial	977	0.9	468	2.1
Industrial	558	0.5	278	1.3
Urban open	1,849	1.7	372	1.7
Transportation	1,422	1.3	198	0.9
Waste disposal	333	0.3	28	0.1
Mining	641	0.6	141	0.6
Subtotal	19,661	18.5	7,461	34.1
Vegetated or Open				
Cropland	3,746	3.5	1,003	4.6
Pasture	2,493	2.4	442	2.0
Forest	65,219	61.6	8,874	40.6
Nonforested wetland	1,929	1.8	236	1.1
Open land	5,130	4.8	1,123	5.1
Woody perennial	4,449	4.2	203	0.9
Salt marsh	1,986	1.9	1,823	8.3
Recreational	1,353	1.3	712	3.3
Subtotal	86,305	81.5	14,416	65.9
Total	105,966	100.0	21,877	100.0

of ecological impact of the existing greater than 60-year-old outfall, it is not ecologically or economically efficient or an example of careful resource management to expend the more than $60 million required to move the outfall. Management must begin to focus on maximizing the resources of the entire bay system, in essence getting the biggest ecological profit for the investment. In the case of the New Bedford outfall extension, a fraction of the funding required for "the pipe" might be better used to save or remediate an equal area of the bay to full resource utilization. While a regional focus is difficult to achieve, the first steps have clearly been taken. The potential for success in this area may be increased by the view that citizens from all of the bay's communities share in the use of the bay proper and are becoming sensitive to the cumulative effects of their local inputs.

Meeting the demands for public access while ensuring environmental protection is one of the biggest challenges facing coastal communities today. Joint cooperation between local and regional managers, regulators, and land planners is crucial to accomplishing ecosystem-level environmental protection in the coastal zone. For Buzzards Bay, environmental policy is set at several levels of government. Federal and state regulations set the general framework primarily for point-source pollutant inputs, while local and regional agencies tend to set the standards for nonpoint-source pollutant inputs (e.g., groundwater). Because of the changing land use patterns around Buzzards Bay, environmental management must be directed not only at current demands and problems, but also toward resolving accumulated impacts from the past and to anticipating future demands, which may either protect or harm coastal resources. Although regulations are in effect to accomplish these objectives, local governments frequently lack the analytical, administrative, or political capacity to implement these

regulations outside of major pollution events. As nutrient-related water quality degradation is becoming increasingly apparent in the smaller harbors and embayments of the bay, sound environmental management policies must be implemented that allow for the intelligent use of these areas while ensuring their protection.

7.4. Relative Sea-level Rise

Although ample scientific evidence exists to support the contention that relative sea level is rising along the Buzzards Bay shoreline (Figs. 6.5 and 6.8), few management strategies are in place to deal with the resulting changes that will ultimately occur along the bay's coast. The desirability of waterfront property has led to significant development along the water's edge, in some cases fortified by seawalls or revetments to protect these properties from storm or erosional damage. Although these constructions provide some protection against storm related wave activity, they cannot provide long-term protection against rising sea levels.

New approaches are being considered to restrict or lessen new development along barrier beaches; however recent court cases (i.e., *Lucas vs. South Carolina Coastal Council*, U.S. Supreme Court, July 1992) have called into question the right of regulatory boards and agencies to restrict economically productive uses of properties without compensatory payment. Other ongoing cases involve the right (or lack thereof) of landowners to protect their property under emergency situations, which frequently involve construction of hard structures currently restricted or prohibited by state or local law. Currently, new construction of seawalls, revetments, and the like is generally prohibited from coastal dunes but can be permitted on coastal banks around Buzzards Bay. Unfortunately, since many of these hard structures were established before current restrictions were put in place, much of the regulation regards repair and replacement and is often on a case-by-case basis, frequently under emergency situations as the result of major coastal storms. Because there are often substantial financial incentives, many of these cases are carried through the various levels of the legal system, being financially difficult for local or regional governmental boards and agencies to pursue. In light of several severe storms that have hit Buzzards Bay over the past two decades, however, the problem has been made at least temporarily apparent, and increased efforts have been made to educate current and prospective owners of waterfront property about the short- and long-term risks of living directly on the water.

Much of the attention given to the problems of waterfront development is focused on building that occurs directly on coastal dunes or banks; however, a significant amount of development also occurs along the wetlands found behind barrier beaches. With rising sea level, barrier beaches naturally migrate landward as do the wetlands behind them (Fig. 6.10). Many of the marsh-front developments have hard structures for protection against major storms, in essence preventing the landward migration of the wetland over time. Increased recognition of the importance of intertidal wetlands to coastal ecology has resulted in more attention to extending buffer zones and developing new approaches to management that take into account the long-term need for wetlands to migrate landward.

Building seawalls and armoring the coast in the face of a continually rising bay and periodic storm events may provide a temporary local solution to land loss by erosion and flooding. Nevertheless over the long term the Buzzards Bay watershed will diminish in size, and the salt marshes, barrier dunes, and beaches will continue the retreat that they began shortly after Buzzards Bay first became an estuary.

Buzzards Bay and its watershed have been continually changing since their formation 16,000 years ago, but the rate of alteration has been accelerating since the colonial era. Human activities have been readily apparent in their effects on terrestrial systems with the original forests being cut for lumber and cleared for agricultural fields, which are now reverting to forest or being developed for residential

settlement. In contrast, the marine systems of the bay have experienced much less alteration. The Buzzards Bay estuary sailed by Gosnold in 1602, by the Wareham-built whaling ship *Pocahontas* leaving on her maiden voyage in 1821, and by the Woods Hole research vessel *Asterias* plying the waters in the 1930's has presented virtually the same face through centuries, with all these ships traversing similar habitats and aquatic ecosystems. But by the time the R/V *Asterias* was decommissioned in the late 1980's, several significant oil spills had occurred, PCB and heavy metal contamination was apparent in the New Bedford region, and more importantly, subtle changes were being observed in the ecology of some of the sensitive shallow embayments of the bay.

It is now clear that significant threats to the productivity and diversity of the bay's animal and plant communities exist, stemming primarily from increased nutrient loading to bay waters. Nutrient inputs in excess of the assimilative capacity of the system are locally altering habitat quality and resulting in restructuring of system ecology. But nutrients, unlike toxics, are natural parts of the biotic systems and therefore need to have their inputs managed, not stopped. Major removal of existing nutrient pools is not necessary. While managing the current and future nutrient loads to levels tolerable to the nearshore systems of Buzzards Bay will be difficult, the initial steps have been made, and the ecological and economic benefits are becoming apparent. Given the resilience of the marine ecosystems of Buzzards Bay and the ongoing management of development-related impacts, we can hope that before the recently commissioned R/V *Asterias (II)* is retired, it will be used to quantify the recovery of currently impacted marginal systems and continue to document the relatively pristine nature of Buzzards Bay proper.

Acknowledgments

First and foremost we thank Rebecca J. Howard of the National Biological Service for her help, extreme patience, and encouragement during the preparation of this manuscript. Clearly without her efforts and faith this monograph would never have been produced. We also thank our friends and colleagues who provided library research, data, and insights and allowed the reproduction of various tables and figures. Much of the information on Buzzards Bay is spread throughout the technical and regulatory literature and is therefore not readily available. The Buzzards Bay Project (BBP) and its director J. Costa were especially helpful in providing BBP technical information and reports; M. Rasmussen and the Coalition for Buzzards Bay were also very helpful. At the Massachusetts state and local level, L. Gil of the Division of Water Pollution Control and G. Heufelder of Barnstable County Health have been studying aspects of the water quality of Buzzards Bay for many years. They provided access to data and reports that we otherwise may have missed, and S. Cadrin of the Division of Marine Fisheries waded through reams of fisheries data to answer our questions. The Massachusetts Natural Heritage and Endangered Species Program was very helpful with our search for information on endangered species, and our thanks go to B. Blodgett and H. Heusmann from the Massachusetts Division of Fisheries and Wildlife for their time and information. We are indebted to B. Kolb of Camp, Dresser, and McKee, Inc., with whom we worked on the New Bedford Outfall ecological studies and who provided much of the best data on outfall and pollutant sources and distributions, and to the Jessie B. Cox Charitable Trust, which provided private support for some of the original data gathering in our ecological research on aspects of nutrient pollution around Buzzards Bay. We also owe a debt of gratitude to D. Ross and the Woods Hole Oceanographic Institute Sea Grant Program, which has supported many of our coastal research projects, helping us to gain a better understanding of the response of these systems to anthropogenic impacts.

We thank the many scientists, students, and scholars in the Woods Hole community who have expended so much time on research into the ecology of the Buzzards Bay ecosystem. Noteworthy in this regard are J. Teal, C. Taylor, and G. Hampson of the Woods Hole Oceanographic Institution, with

whom we have collaborated for many years, D. Terkla and P. Doeringer of Boston University who worked with us on the economic impacts of environmental change for the bay, and J. McDowell for making available technical data on scallop fisheries and pollutants. D. Bourne and B. Livingstone were of great assistance in providing historic texts and their own insights on fisheries and the early days of the bay. Finally, we thank our lab group—S. Brown-Leger, N. Millham, D. Schlezinger, D. White, and M. Zinn—for putting up with us during data gathering and writing.

This manuscript was processed for printing using Pagemaker software at the National Wetlands Research Center by Sue Lauritzen. This manuscript is contribution number 8177 from the Woods Hole Oceanographic Institution.

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REPORT DOCUMENTATION PAGE

Form approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE
September 1996

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Ecology of Buzzards Bay: An Estuarine Profile

5. FUNDING NUMBERS

6. AUTHOR(S)
B.L. Howes and D.D. Goehringer

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSES
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Woods Hole Oceanographic Institution
Woods Hole, MA 02543

Coastal Ecological Research Institute
at Woods Hole
Woods Hole, MA 02543

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESSES
U.S. Department of the Interior
National Biological Service
Washington, DC 20240

10. SPONSORING, MONITORING AGENCY REPORT NUMBER
Biological Report 31

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Release unlimited. NTIS, DoDD

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Buzzards Bay remains one of the few relatively pristine bays in the metropolitan corridor from Washington to Boston. The bay and its surrounding marshes and uplands have provided a variety of biotic resources not only to European settlers over nearly 400 years but also to the Native Americans who relied on this estuary for thousands of years before them. Today the uplands are divided between 18 communities, and while the bay is still exploited for its biotic resources, its aesthetic and recreational values add to the growing concern to preserve its environmental quality. At the same time, it has become clear that the health of the Buzzards Bay ecosystem, like almost all estuarine systems, is controlled not just by processes within the bay waters themselves but also by inputs from the surrounding uplands as well. Therefore, to properly understand and manage this system, it is important to detail activities and land use patterns within the watershed as well as within the tidal reach of the bay waters. This combined watershed-bay system is referred to as the "Buzzards Bay Ecosystem" and is the necessary frame of reference for understanding the biotic structure of the bay and for managing and conserving its resources.

This community profile provides an overview of the ecology of the Buzzards Bay ecosystem. It is not intended to represent an all-inclusive review of the literature; instead it is an attempt to present key features of the bay in a readily accessible form and to summarize the dominant ecological processes that structure the bay environment. Because the current and future environmental health of these types of embayments can be directly influenced by activities within contributing watersheds, understanding the interactions between land and sea is an important component to understanding the ecosystem as a whole. The subjects addressed in this profile, therefore, focus not only on the open bay waters but also on the ecology of Buzzards Bay within its watershed including management issues and the difficulties in balancing demands for access and development while protecting water quality.

14. SUBJECT TERMS (Keywords)
Buzzards Bay, estuarine ecology, ecosystem, watershed

15. NUMBER OF PAGES
vi + 141 pp.

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

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U.S. Department of the Interior
National Biological Service

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This responsibility includes fostering the sound use of our lands and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities.